Dating Iberian prehistoric rock art: methods, sampling, data, limits and interpretations

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Abstract

Prehistoric rock art dating has been one of the major challenges since its discovery and recognition. The methods have evolved through the last century, beginning with the study of superpositions and style up to the application of numeric methods since the 1990s. The objective of this paper is to evaluate and publish an up-to-date database of all of the numerical dates of Iberian prehistoric rock art sites. For this purpose, the manuscript reviews all the methods applied to Iberian rock art by discussing its limits, the sampling involved, and the problems affecting the results. Subsequently, we present and discuss the most relevant results by cultural tradition (Palaeolithic, Levantine, Schematic and Megalithic rock art). Finally, we reflect on the future of rock art dating: most of the motifs are not datable by numeric methods, meaning we still have to combine traditional with numerical methods; but also, further work on the problems affecting these methods to be able to create a chronological framework that allows to address other issues such as group mobility, cultural networks, and reutilisation of symbolic elements, to name a few.

Keywords: chronology, Palaeolithic rock art, Levantine rock art, Schematic rock art, Megalithic rock art, radiocarbon, U-series, Thermoluminiscence, Iberian Peninsula

1. Introduction

Dating rock art is one of the major challenges of rock art research. It is crucial to maintain an accurate chronological control of the rock art and to place images and styles in their cultural context (Domingo et al., 2008). For over a century this matter has generated intense debates (Breuil, 1952; Leroi-Gourhan, 1965; Lorblanchet and Bahn, 1993; Hedges et al., 1998; Valladas and Clottes, 2003; Valladas et al., 2006, 2013; Pettitt and Pike, 2007; Pike et al., 2017) and these debates are still ongoing today. For decades, rock art has been mainly dated through relative dating techniques, with style and the analysis of superimpositions being widely used as chronological markers.

The application of AMS radiocarbon dating to portable objects (Barandiarán, 1988) and rock art in Altamira, El Castillo and Niaux caves (Valladas, 1992) provided the first direct dates associated with Palaeolithic representations in western Europe. Since then, that method and other dating techniques, like thermoluminescence and more recently U-series (Arias et al., 1998; Bischoff et al., 2003), have been gradually applied to several European Palaeolithic and Post-Palaeolithic rock art sites in an attempt to refine the chronologies of several rock art traditions (including Levantine, Schematic and Megalithic art).

The results of the different methods employed so far have been useful to advance in discussions on how and when the first art developed (García-Diez and Ochoa 2019) and how it evolved over time. Despite constraints arising from the type of sample, the relation to the graphic process, the poor preservation of the art, the amount of sample needed, contamination, potential pitfalls in pre-treatment protocols, contradictory data results, etc. (see Hedges et al., 1998; Valladas, 1999, 2003; Scharebereiter-Gurtner et al., 2002; Clottes and Valladas, 2003; Valladas et al., 2006; Pettitt et al., 2009; Alcolea & Balbín, 2007; Combier and Jouve, 2014; Pettitt and Bahn, 2014; Hoffmann et al., 2016; Pike et al., 2017), the different techniques used and the results obtained over these years have fostered reflections on the origin and development of each prehistoric art tradition, posing new questions and sometimes challenging previous assumptions.

The Iberian Peninsula is an interesting geographical space to explore the evolution of prehistoric art. This territory has preserved different rock art traditions of interest to explore continuities and changes in the graphic practices of prehistoric societies, from the Palaeolithic to the end of Prehistory. For decades, evolutionary approaches to rock art established a linear evolution from simple to complex, starting with archaic and basic depictions that slowly evolved into more technically and stylistically complex motifs during the late Upper Palaeolithic (Piette, 1907; Breuil, 1952), then turned into stylised and schematic depictions (Acosta, 1968; Beltrán, 1968; Cruz and Vicent, 2007) during the Holocene. The transition between the different phases –Palaeolithic and early Holocene, Levantine and Schematic rock art– is still under discussion (see historiographical discussion in Ripoll, 2001; Cruz and Vicent, 2007; and García Arranz et al., 2012; Bueno-Ramirez et al., 2007a; Bueno-Ramirez & Balbín Behrmann, 2009).

This paper offers an updated synthesis of the dating methods used to date Iberian rock art, including a compilation of all direct dates published so far for prehistoric rock art in the Iberian Peninsula and discusses in detail the available information, as well as their contributions and constraints. The results are of interest to better tie specific motifs, subject matter and techniques to particular timeframes and traditions, which is extremely useful to reflect on how rock art developed in prehistoric times and to assess the validity of purely stylistic approaches to the art. Finally, we will evaluate their archaeological significance in chrono-cultural terms.

2. Rock art dating methods

For nearly a century, relative dating methods have been the main tool available to create relative sequences and relate rock art to wide cultural contexts. By establishing consistent associations between rock art and dated portable art based on stylistic similarities (Breuil, 1952; Martí and Hernández, 1988) and analysing ‘parietal stratigraphy’ (Breuil, 1905; Beltrán, 1968), researchers ordered the art from earliest to latest and created artistic sequences, some of which are still in use today. While ‘parietal stratigraphy’ provides a sequence of painting events, the temporal interval between each event (from a short period of time to thousands of years) cannot be estimated through stylistic analysis (Domingo, 2008: 105). Also, the limited number of superimpositions challenges the application of this method. The more recent application of new laboratory techniques to date rock art gave this method a new twist by providing a minimum or maximum date for those depictions located under or over a directly-dated graphic unit, as well as those which are considered stylistically equivalent.

Comparing rock art to dated portable evidence (e.g. plaquettes, osseous artefacts, ceramics) based on stylistic similarities (Breuil, 1952; Martí and Hernández, 1988), has been the key for building most of the current chronological frameworks used in both Palaeolithic and post-Palaeolithic rock art and it is the only available tool that we currently have to estimate the age of most prehistoric rock art (Guy, 2011; Domingo and Fiore, 2014). The use of stylistic approaches to establish rock art sequences dates back to the authentication of Altamira in 1902. The functionality of this method is based on the certainty of the stratigraphic position, and thus, the date, of the object that is used for the comparison. The procedure is, currently, to isolate stylistic criteria of a particular depiction and limit the comparison to the same taxa and geographical area. Despite the use in other archaeological strands –other types of artefacts are basically dated in the same way– this method still arouses reservations, since there are technical differences between portable and rock art series. It is also complicated by comparisons that some authors make without basis or sound stylistic justification; for example, the extensive discussion on the chronological value of ceramic decoration and its comparison with Levantine art (Mateo, 2008). We are also challenged by the lack, or dearth, of portable art in some phases such as the Early Palaeolithic (Ochoa et al., 2019) or Levantine rock art (Domingo, 2005: 77-81). We also have to admit that identical or very similar styles might not correspond to the same phase, creating a circular problem. Style operates at different scales, such as individual, group or intra/inter-group identity scales and it might have served different purposes (Domingo, 2005). As such, style might have at least two opposing readings: morpho-stylistic similarity implies a temporary specific synchrony defined by the graphic links established between portable and rock art. On the other hand, those similarities might correspond to a graphic tradition that could have lasted for some time, even transcending the temporal delimitation of lithic techno-complexes, and was transmitted through different mechanisms that entail a high level of graphic normalisation in the construction of the depictions (Ochoa et al., 2019). To summarise, stylistic comparisons are a basic tool to date rock art, as most depictions cannot be dated by other means, but we have to be aware of its caveats and thus, apply it within reason.

Other traditional methods used for rock art dating include the closure of a cave at a datable point in time, providing a minimum date (e.g. Rivière, 1897); direct association with the stratigraphy of a site, which may either cover the decorated walls (e.g. Aubry and Baptista, 2000) or detached pieces of the ceiling or the wall (e.g. David et al., 2013); depictions of datable subject matter, such as extinct fauna, specific material culture, and so forth. Ethnographic knowledge can also contribute to date recent art in particular parts of the world (e.g. May et al., 2017). The relation to geological events that can be dated independently by any other means, allow a minimum age for the art to be defined, providing a date that can be complemented with stylistic analysis or with direct dating. If the authenticity of the rock art is in question, these geological events might be the key to prove their prehistoric date (García-Diez and Ochoa, 2013).

The potential link between the rock art of a particular place and datable archaeological remains identified in the surroundings has also been used to suggest potential dates for rock art when other direct dating techniques are not applicable (e.g. Clottes, 1993; Medina et al., 2018; Oliveira and Oliveira, 2015). However, we need to keep in mind the risks of these sorts of associations, since the same place could have been visited multiple times for multiple purposes at different points in time, and as such two different items could have been left in two different periods even if we find them close together today. Thus, the relationship between the art and the dated sediments, or artefacts of the surroundings is controversial when there is no direct connection between them. This includes dating artefacts inserted in crevices in close proximity of rock art. Moreover, sedimentation is usually very slow inside caves. For these reasons, we reject the use of these types of dates, due to the questionable link between, possibly, two different events that may or may not be related, as they could result from a re-use of an already 'marked' area (Lorblanchet, 1981, 2010; García-Diez et al., 2015; Clottes and Simonnet, 1990; Valladas et al., 1990; Ochoa and García-Diez, 2014).

Since the late 1980s and 1990s, the application of chronometric dating techniques to prehistoric rock art across the world (for a list of examples see Rowe, 2012) opened new perspectives and debates. In the Iberian Peninsula mainly three of these techniques have been applied: radiocarbon, uranium series and thermoluminescence. The earliest to be applied was the former. However, after a first bout of dates, the questions and doubts arising from the results (e.g. Fortea, 2002; Steelman et al., 2005) and the fact that this technique destroys the art (even though today microsamples are used) slowed down the application. Regarding U-series, the method has been developed and improved to date small samples of calcite underlying or overlying rock art and has been applied to both Palaeolithic and Post-Palaeolithic rock art sites (Pike et al., 2012; Rogerio-Candelera et al., 2018). The results obtained are promising. However part of the scientific community has not accepted them fully, especially as some results have opened new debates on the potential relationship between rock art and European Neanderthal populations (Hoffmann et al., 2018a). T~~Finally, t~~hermoluminescence was briefly tested to date calcite formations (Arias et al., 1998; González-Sainz and San Miguel, 2001; Villaverde et al., 2009). However, the numerous geological variables affecting the samples generate a large margin of error, preventing relevant dates being obtained. We shall evaluate the potential and limits of these techniques when applied to rock art. In the last few years the application of OSL dating has been proposed for megalithic rock art in different ways: dating the sediment covering the rocks or the last time the rocks were exposed to sunlight. However, this technique is in the early stages of development and there are still no published dates that pertain to megalithic orthostats that have rock art (Bueno, 2007b; López-Romero, 2011).

2.1. Radiocarbon (C^{14}AMS): first numeric protocol

Application of C^{14} dating to Palaeolithic rock art started in the 1990s in France (Valladas, 1992). It was reliant on the AMS (Accelerator Mass Spectrometer) methodology owing to the small samples taken from the depictions. Its limit is currently 50,000 years BP. However, this is due to the precision of the measuring equipment and sample size, and in the future this time constraint might be solved and expanded. This is currently the only method allowing direct dating of the art by dating the charcoal with which depictions were produced, although we have to be aware of the ‘old wood’ problem (Pettitt and Pike, 2007). It also allows the dating of organic material that might be part of the pigment such as fibres, binding agents and charcoal inclusions in depictions; or somehow related to it, such as calcium oxalates and organic deposits in mineral accretions. Any of the above-mentioned situations, would provide a minimum date for a motif.

The protocol for dating depends on the sample. For charcoal, at least originally, the sampling occurred in several parts of the depiction if the amount of pigment in one area was insufficient (Valladas et al., 2006). But this multiple sampling of the same motif generated several problems: the possibility of mixing samples of the original motifs with those resulting from repainting; and the bigger the area sampled, the greater the possibility of dealing with different types of contaminants. Today it is understood that to avoid this, the sample should be taken from a single chunk, first to be able to certify that it is, indeed, charcoal but also to avoid the presence of rock, humic acids and other unknown contaminants. The archaeologist has to be confident about the direct relation between the sample and the event that needs to be dated and how the sample integrates in the whole ensemble (Batten et al., 1986; Pettitt and Pike, 2007).

The initial weight of the sample depends on its type and composition, which usually includes charcoal and calcite/limestone in different proportions (Valladas et al., 2001). The decontamination process generates at least two fractions: humic, which still contains contaminants from the decomposition of organic materials in the cave walls (Valladas et al., 2006), and pure carbon fraction (also named humin). According to the Gif-sur-Ivette laboratory, the most reliable dates are obtained from a mass at least 500 µg (Fortea, 2007). Less quantity would compromise the reliability of the result due to the possibility of the presence of young carbon or dead carbon from different sources. The humic fraction was frequently dated by the Gif-sur-Ivette laboratory to use as a marker for the decontamination process (Batten et al., 1986; Valladas and Tisnérat-Laborde, 2000). If both results were statistically the same it would indicate a successful decontamination. However, the results from the fractions were frequently inconsistent and the interpretation varied depending on the specific cases. Valladas proposes that, when the humic fraction result is older, we should consider it more reliable due to excessive decontamination, eliminating part of the pigment's carbon. If the humic fraction result is younger, the humin is more reliable, as the humic might still contain contaminants (Valladas et al., 2006). Clottes and Valladas (2003) claim that all anomalous results have an explanation; they have however failed to address the problems linked to radiocarbon in the specific case of rock art.

After the Chauvet dates were announced, several research articles have been published calling out the problems affecting the application of the method to rock art (Pettitt and Bahn, 2003; Valladas et al., 2005; Pettitt et al., 2009; Sadier et al., 2012; Balbín-Behrmann, 2014; Lorblanchet, 2014). Combier and Jouve (2012) proposed the use of the isotopic fraction to define the origin of the charcoal. However, the idea has been rejected as the value is measured in different conditions, and it should be obtained in a different sample in order to be useful (Fontugne et al., 2014).

In a few cases, researchers applied plasma oxidation to process charcoal and other organic components of rock art rather than the traditional acid baths (Steelman and Rowe, 2012). Plasma oxidation avoids the use of extensive acid pre-treatment, minimizing the loss of organic material. However, this protocol does not completely eliminate modern contaminants leaving open the possibility of modern carbon. This procedure was used in an archaeological site for the Pleistocene-Holocene transition and in most of the Megalithic samples in Iberian Peninsula (Steelman et al., 2017; Carrera and Fábregas-Valcarce, 2002, 2006). Oxalates have also been dated by radiocarbon AMS to provide a minimum date for Post-Palaeolithic rock art in the Iberian Peninsula (Ruiz et al., 2006). Oxalates are carbonate layers with a biological component that grow on rock surfaces in thin layers. Rock art is frequently in between these layers so the most important question is the physical and temporal relationship between the oxalate layer and the pictorial layer. For this reason, the most important point is that the sampling process has to be carried out knowing the stratigraphic order between the two, ideally directly over the motif. However, this is hardly ever done because of the relative thinness of the oxalate layer. Moreover, the potential contamination of the samples with old carbon during the process of formation of the oxalate crusts has led researchers to question the results. The problem here is determining the source of the carbon dated as well as the correct relation with the paintings (Bednarik, 2001: 121-122; Rowe, 2001: 146-47; Dorn, 2001: 171).

The date obtained through radiocarbon analysis is, following international convention, expressed in years BP (Before Present, defined as before 1950) with 68.4% confidence. Calibration and considering the results with 95.4% confidence are still not generalised in the field, generating problems in reporting.

2.2. Uranium series dating: contextual data for prehistoric art

Until the early 2000s these analyses, based on the U^{234} and Th^{230} equilibrium, were limited to palaeoenvironmental research, the basis to establish calibration curves for radiocarbon, and the dating of early and middle Palaeolithic artefacts. The application to rock art began with Palaeolithic cave art. The samples needed, calcite formations, are abundant in cave environments so it is the ideal method to date motifs that were engraved or depicted with inorganic pigments. The method is based on the absence of Th^{230} in the sample. Once the calcite crystallises, it becomes a closed system and the U^{234} starts to decay, generating several by-products, including Th^{230} (Liritzis, 1987).

The measurement of the ratio of these elements provides a date. The first problem this method encounters is the frequent presence of detrital contamination which brings Th^{230} to the sample. The amount of Th^{232}, also a detrital inclusion, allows a correction factor to be applied that increases the statistical error. The second problem is that the 'closed system' is not easily verifiable, as the calcite formation may have reactivated at some point; 'leaching' and modifying the original ratios. The solution to this problem is taking multiple samples in a stratigraphic order. If the results for layers are coherent – the sample closest to the pigment is the oldest and the farthest is the youngest– it means the sample can be considered a closed system and the date is reliable.

The samples can be smaller than 1 mg, but the outcome depends on their quality (presence of detrital matter and crystallization). The samples must be taken by dating experts accompanied by archaeologists to avoid problems and to ensure the relation of the sample and the motif. The samples must be either directly over (for an *ante quem* date) or directly under (for a *post quem* date) the motif (Pike et al., 2012b; 2017). To avoid contamination and damage to the motif, the sampling must end as soon as the overlying calcite becomes transparent or flecks of pigment are evident (Hoffmann et al., 2016).

Dates obtained are calendar dates –they do not need to be calibrated– and are expressed in ky with an error in 95% confidence (Hoffmann et al., 2016). Its interpretation depends on the relation to the motif: if the calcite was overlying the motif, the error is deducted from the result and the depiction is considered older than that. If it is underlying the motif, the error is added and the depiction is younger than the date obtained.

The more extensive application of this method in the last few years has generated ample debate on the subject. Several authors (Pons-Branchu et al., 2014; 2015; Sauvet et al., 2015) criticise the method on the basis of the detrital corrections and the frequency of an open system. They also mention that most of the calcite growth comes from the early Holocene making the results irrelevant and that the underlying samples are not relevant to the execution of the art and obtaining them damages the motif. The authors make the point of using different methods to test the validity of the system and request more in-depth information on the process. The team led by A. Pike and D. Hoffmann have addressed these comments by publishing several articles on the method and the process, with special emphasis on the problems and how they are solved (Hoffmann et al., 2016; 2018c; Pike et al., 2017). They also reported new dates (Hoffmann et al., 2018a).

Recently, radiocarbon dating of calcite crusts has been tested to date rock art (Valladas et al., 2017). However, like oxalate dating, this technique is highly unreliable. It suffers from the same problems as U series dating (leaching and contamination) combined with the presence of modern contamination and/or dead carbon from cave walls, making it difficult to predict the reliability of the result.

2.3. Thermoluminiscence: a failed experiment

In the late 1990s, the possibility of dating calcite over and under rock art motifs through thermoluminescence (TL) was explored for Upper Palaeolithic depictions (Arias et al., 1998; González-Sainz and San Miguel, 2001; Villaverde et al., 2009). This method is frequently used to date other archaeological materials such as ceramics or sediments. However, soon after these first experiments, it was determined that the dating of calcite exposed to different variables (humidity, growth rate, human/animal occupation, …) generates dates that have a large error (Beneitez et al., 2001), around 10%, so it is not able to provide useful ranges, as they cover the whole Upper Palaeolithic. The method is based on several environmental doses that should be measured at least for a year, and even after that, their variability makes them difficult to extrapolate. A full account of the application of the method to rock art can be found in Arias et al. (1998) and Beneitez et al. (2001). All the dates obtained by TL for Palaeolithic rock art were processed at the UAM Dating and Radiochemistry laboratory with a Riso-TLDA-10 high sensitivity thermoluminiscence equipment.

3. Results

3.1. Upper Palaeolithic rock art

The results obtained for Upper Palaeolithic rock art are very variable. Up to now, 117 radiocarbon dates, ~~124~~ 137 U-series dates and 15 TL results have been published (Tables 1, 2 and 3). The origin of art in Western Europe has been determined by ~~the latest paper on~~ U-series dating: a sign in La Pasiega indicates the earliest art dates back to at least 65,000 years ago (Hoffmann et al., 2018a). Slightly younger are the dates for a handprint and a red stain in Maltravieso and Ardales. Belonging to the Early Upper Palaeolithic, other signs such as a claviform in Altamira and a red disk and negative handprints in El Castillo and Fuente del Trucho with overlying calcite formations, were also dated by U-series (Pike et al., 2012a, 2012b; García-Diez et al., 2013; Hoffmann et al. 2017). These results have still not been widely accepted by the scientific community (Pons-Branchu et al., 2014, 2015; Sauvet et al., 2015; Slimak et al., 2018; White et al., 2019). However, the team in charge has been replying to the questions put forward by other researchers (Hoffmann et al., 2016; 2018c, 2020; Pike et al., 2017).

Table 1. Iberian Upper Palaeolithic radiocarbon dates. The table contains the information pertaining to each cave, classified as follows: Cave, Location, Graphic Unit, Laboratory number, Method (Direct C14 and C14SO= Archaeological stratum overlies art), Type of Sample (CP=Pure Charcoal; FH=Humic Fraction; UNK: unknown); Date, Error, Calibrated range (INTCAL13–Reimer et al., 2013; Bronk-Ramsey et al., 2009), and reference of the original publication.

Table 2. Iberian Upper Palaeolithic U-series dates. The table contains the information pertaining to each cave, classified as follows: Site, Location, Graphic Unit, Laboratory number, Method (U-series), Type of sample (AQ= Ante Quem, PQ= Post Quem); Corrected Age and error; Date, Error, Age and reference of the original publication.

Table 3. Iberian Upper Palaeolithic thermoluminescence dates. The table contains the information pertaining to each cave, classified as follows: Site, Location, Graphic Unit, Laboratory number, Method (TL), Type of sample (AQ= Ante Quem, PQ= Post Quem; Date, Error, Age and reference of the original publication.

In Iberia, the first figurative art seems to have appeared between the Aurignacian and the Gravettian, with the dating of the Tito Bustillo anthropomorphic figure (Pike et al., 2012b). We also have relevant results for the Gravettian and the Solutrean obtained by U-series. For the Gravettian, several motifs were sampled in La Garma. The results indicate that the aurochs panel would be older than 26ky and a negative handprint is older than 29ky (Arias, Ontañón, 2008). However, these were some of the first attempts to use this technique and the samples were not taken immediately over the motifs to avoid damage. In Fuente del Trucho, a sampled bovid result indicates it was traced over 29ky ago (Hoffmann et al. 2017). For the Solutrean, a dotted horse traced in red was dated to over 22 ky (Pike et al., 2012b) in Altamira; and in El Castillo a negative handprint was estimated to be over 24.2 ky (García-Diez et al., 2015).

As of now, these results are the most relevant data provided by U-series dating; out of 137~~2~~ dates, the results largely correspond to the Holocene (Pike et al., 2012b; Hoffmann et al., 2018a). This is the main drawback of this technique: dating a geological process can give any result. However, it can provide very relevant results for the earliest phases of rock art which were largely undated until recently. Hopefully, the development of this technique and the extensive application to more figurative and non-figurative representations will allow different phases to be established for Pre-Magdalenian art in the near future.

Different types of problems are encountered when analysing radiocarbon results for the Upper Palaeolithic. For Pre-Magdalenian phases, all of the results obtained are problematic. The case of Candamo is almost paradigmatic: a series of black dots traced over a couple of yellow aurochs have been dated after three different samplings, each providing a set of different results: Aurignacian, Gravettian/Solutrean and Lower Magdalenian (Fortea, 2000, 2007; Corchón et al., 2014). After the first puzzling result, Fortea determined the samples were at least partially composed of bone and certified the presence of bacterial contamination. He also provided other possibilities for the results such as the presence of fossil carbon, repainting etc. There is another result from Candamo, associated with the Gravettian, a 'Niaux type' bison (29), chosen because of its placement over an Altamira-El Castillo type hind and under two deer (6 and 7). The result is surprising because it corresponds to a very well dated –by portable art and rock art radiocarbon– style but it is also over a hind that has been dated to the Lower Magdalenian by the same means (Fortea, 2007). In El Castillo, the ensemble 25-27 was dated to the Solutrean but the two results, both from a humin fraction, are not statistically similar (Moure et al., 1996). This is a widespread problem with the samples taken in El Castillo.

In Altamira the results for the Polychrome ceiling bison are also scattered, and unexpectedly correspond to the Lower Magdalenian. Some of the dates show evident problems with statistically different dates for the same motif; the ensemble was considered synchronic corresponding, at least, to the Middle Magdalenian and the results point to a longer timespan (Moure et al., 1996; Valladas et al., 2001). An ibex from El Castillo rendered two statistically incompatible dates; similarly, the 18/19 bison ensemble provides disperse dates between the three depictions, which were considered synchronic and Middle/Upper Magdalenian, and even for the same depiction (Valladas, 1992; Moure et al., 1996; Moure and González-Sainz, 2000).

In Ekain and Tito Bustillo caves, a series of horses in the same style, associated with the last phases of the Magdalenian, were sampled. For Ekain only one horse (29) rendered Palaeolithic dates, in the Lower Magdalenian, combined with the Post-Palaeolithic dates for the other three horses sampled, this attests a problem, possibly contamination

(González-Sainz, 2005). The same occurred with the Tito Bustillo horses: with seven dates for horses 56 and 58, the results are scattered all through the Magdalenian, some dates barely overlap, some are statistically different and some other results are Post-Palaeolithic (Balbín-Behrmann et al., 2003; Balbín & Alcolea, 2013; Fortea, 2007).

For the late Magdalenian, the dates from Llonín (Fortea, 2007) are inconsistent –spanning from the Middle Magdalenian to the Azilian– and the authors mention the possibility of contamination. Similarly in Las Monedas, the dates for the ibex 16 present problems between the humin and humic fractions (González-Sainz, 2005).

There are results that do not clash with the expected date; however, they are usually single dates as at La Pileta and Nerja (Sanchidrián and Márquez, 2003) (Solutrean), Altamira's black series –a black track, a sign and a line under a striated El Castillo-Altamira hind–(Moure et al., 1996); deer 20 in Chimeneas (Lower Magdalenian) (Moure et al., 1996; González-Sainz, 1999); a vertical bison in La Garma (Middle Magdalenian) (Arias et al., 2008), horse 20 in Monedas (González-Sainz, 1999; 2005), bison 3 in Urdiales (Valladas et al., 2013) and ibex SGB.VI.1 in Candamo (Late Magdalenian) (Corchón et al., 2013). Additionally, there are some consistent cases of several coherent dates, such as the bison in La Covaciella (Fortea et al., 1995), ibex 67 in La Pasiega (Middle Magdalenian) (González-Sainz, 2005); bison 3 in Tito Bustillo (Fortea, 2007) and bison 88 in La Pasiega (González-Sainz, 2005) (Late Magdalenian).

Finally, 24 Palaeolithic motifs –in Ekain, Tito Bustillo, El Castillo, La Cullalvera, Llonín, El Pindal, Santimamiñe, El Buxu, La Sotarriza and Candamo (Valladas, 1992; Moure and González-Sainz, 2000; Fortea, 2007)– provided a Post-Palaeolithic date. This high number of representations that are, stylistically, Palaeolithic combined with the problems stated in the previous paragraphs show the important technical problems and/or archaeological limitations regarding radiocarbon sampling for Palaeolithic cave art due to the fact that they account for more than 20% of the whole dated sample.

3.2. Levantine rock art (LRA)

Failure to apply radiometric dating techniques to directly date LRA –owing to the absence of organic matter in the pigment compounds– left it on the sidelines of major debates starting in the 1980s and 1990s. These revolved around the impact of these techniques both to date the art and to question previous stylistic sequencing. Various attempts to obtain date estimates using indirect radiometric dating techniques (dating calcium oxalate admixed in calcite layers) (Fullola, in press; Ruiz et al., 2006, 2012; Viñas et al., 2016), show a desperate need to date this art. While these initiatives represented a step forward, unfortunately they were unsuccessful, since both the technique and the chronological relationship of the sampled crusts with the paintings are controversial (Domingo, 2008) (Table 4).

Table 4. Iberian Levantine, Schematic and Megalithic radiocarbon dates. The table contains the information pertaining to each cave, classified as follows: Site, Location, Artistic tradition, Graphic Unit, Laboratory number, Method (C14, C14Ox=C14 on oxalate crusts and C14PlOx= C14 on oxalate crusts processed by plasma oxidation), Type of Sample (CP=Pure Charcoal; FH=Humic Fraction; UNK= unknown); Date, Error, Calibrated range BP and Calibrated age BC (INTCAL13–Reimer et al., 2013; Bronk-Ramsey et al., 2009), and reference of the original publication.

The first attempts go back to 1999. The collaboration between the Oxford Radiocarbon Unit led by P. Pettitt and J. Fullola from the Universitat de Barcelona dated oxalate formations over Post-Palaeolithic art in Ermites de la Serra de la Pietat site (Ulldecona, Tarragona). While they obtained four results for four motifs, the dates remained unpublished since the origin of the dated carbon was unclear (whether it was part of the organic matter of the pigment or some sort of contamination (e.g. fungus, organic deposits) (Fullola, in press).

From the mid-2000s onwards, new attempts have used the same technique (Ruíz et al., 2006; Ruiz et al., 2009, 2012; Viñas et al., 2016). However, despite the constraints inherent to this technique, this time the samples were not even taken directly over the paintings but nearby, so the necessary stratigraphic relation to obtain a minimum or maximum date is not met.

The number of samples obtained by Viñas et al. (2016) was large. However, many of them did not provide satisfactory results due to lack of carbon or the coexistence of multiple layers of oxalates and other recent additions. In these cases the results displayed large standard deviations (Viñas et al., 2016).

Thus, reliable dates for Levantine rock art are still lacking.

3.3. Schematic art

Three types of analysis have been applied to date schematic representations: U-series, and radiocarbon on black pigment and on oxalate crusts. These have produced 16 results so far (Table 4).

Regarding charcoal samples, seven dates were obtained for several types of motifs described as Schematic. However, on closer inspection, only three of them were of drawings: an anthropomorphic figure and a grill sign in Galería del Sílex (García-Diez et al., 2005) and a pectiniform in La Pileta (Sanchidrián and Márquez, 2003). The anthropomorph in Sílex has a considerable error giving a range between the early 3^{rd} millennium and late 2^{nd} millennium BC. The sample from La Pileta resulted in a very recent date, the 2^{nd} millennium BC, marking the end of this tradition. The rest of the charcoal samples are of black trace marks that are related to schematic art. In the case of Sala de la Fuente in Ojo Guareña, underlying and overlying the megalithic style engravings, the results obtained range from the beginning of the third millennium to the beginning of the second millennium BC (Gómez-Barrera et al., 2000). Similarly, in Laja Alta a non-figurative black mark was dated to the 4^{th} millennium BC: however, it is unrelated to the rest of the motifs. Additionally, the authors indicate that the sample was small, which did not allow the δ^{13} ratio to be obtained and possibly making the result questionable (Morgado et al., 2018).

U-series dating was attempted in the Matacabras Rockshelter, this was the first application of this technique to open-air sites (Table 5). Three results in stratigraphic order were obtained providing an *ante quem* date, indicating that the motif was executed before 3800 BC. However, the authors considered this date unreliable due to the significant presence of detrital contamination (Rogerio-Candelera et al., 2018).

Table 5. Iberian Schematic U-series dates. The table contains the information pertaining to each cave, classified as follows: Site, Location, Graphic Unit, Laboratory number, Method (U-series), Type of sample (AQ= Ante Quem, PQ= Post Quem); Corrected Age and error; Date, Error, Age and reference of the original publication

Regarding oxalate crust dating, the situation is very similar to the one commented above in the section about Levantine art. The sites dated were Abrigo de los Oculados, Selva Pascuala, Tío Modesto and Ermites IV (Ruíz et al., 2006; Ruiz et al., 2009; 2012; Viñas et al., 2016). Eight dates have been published, all within the expected ranges for this cultural tradition. However, the same problems linked to the method occur: the samples were not taken directly over the depictions, making the date unrelated to the archaeological event. Moreover, the lack of understanding of the geological processes that created the oxalate crusts makes the sampling problematic.

3.4. Megalithic art

Only eleven direct~~ten~~ dates have been obtained as of now for Iberian Megalithic art (Table 4). All from northeastern Iberia, with one site dated in Portugal (Antelas) (Cruz,

1995) and eight~~seven~~ sites (with ten~~nine~~ results) in Galicia (Pedra Moura, Casota do Páramo, Pedra Cuberta, Monte dos Marxos, Forno dos Mouros, Anta de Serramo and Coto dos Mouros, Os Muiños) (Carrera and Fábregas-Valcarce, 2002, 2006; Carrera, 2008). Samples consisted mainly of black pigments, sometimes combined with the underlying white layer that is frequently applied between the rock and the depictions, or in between layers. All of these were identified to be charcoal. In one case, Monte dos Marxos, two pictorial layers were sampled obtaining stratigraphically sound results pointing to a repainting of the motifs, possibly accompanied by an architectural remodelling of the site, a dolmen with corridor. The method used to extract the carbon was Plasma oxidation, which would be able to obtain, in theory, all the carbon including that present in the binding agent. The authors consider the dates *post quem* in all cases to avoid the 'old wood' problem; the results indicate that the depictions correspond to foundational moments between 5050-3000 cal BC. However, the archaeological contexts of these particular sites are largely undated; data only exists in one case (Antelas) and it points towards a lag between the construction and the decoration. In the case of Monte dos Marxos, the dates attest to prolonged use of the monument, maintaining very similar decoration between phases, indicating continuity in the cultural/symbolic trends. The attempts to date the binding agents were unsuccessful, probably due to the need of a larger sample, and it has not been tried since because of the ethical problems.

These results corroborate the data provided by archaeological contexts for the rest of the Iberian Peninsula (Bueno-Ramirez et al., 2007b) where no dating has been attempted due to the late recognition of paint in Megalithic rock art and the problems the dating technique displayed in other attempts in European megalithic art.

3.5. Post-Palaeolithic dates: Schematic-Abstract art?

~~Thirteen~~ Ten radiocarbon dates from Covalanas, El Calero II, Portillo de Arenal, Coburrullo, Cueva Roja, Arco A and Cova Negra (Moure and González-Sainz, 2000; Muñoz and Morlote, 2000; García-Diez and González-Morales, 2003) correspond to black traces (Table 6). These had been assimilated to a Bronze Age tradition named 'Schematic-Abstract Art'. However, the results obtained have shown that this black series does not correspond to a specific chronology but spans from the Upper Palaeolithic to Medieval times. Its functionality could be related to torch rekindling, transit tracks or possibly symbolic intention in some cases.

Table 6. Iberian black traces dates. The table contains the information pertaining to each cave, classified as follows: Cave, Location, Graphic Unit, Laboratory number, Method (Direct C14 and C14SO= Archaeological stratum overlies art), Type of Sample (CP=Pure Charcoal; FH=Humic Fraction; UNK= unknouwn); Date, Error, Calibrated range (INTCAL13–Reimer et al., 2013; Bronk-Ramsey et al., 2009), and reference of the original publication.

4. Discussion

Despite being available for almost 30 years, the application of radiometric dating techniques to rock art is a 'young' discipline, with ~~155~~ 156 radiocarbon dates, 140~~26~~ U-series dates and 15 thermoluminiscence dates results for Iberian prehistoric rock art. This means that the results must be carefully analysed, considering all the problems affecting the rock art samples in each specific case, to continue to refine the methods and the chronologies of prehistoric rock art.

Sampling must be a well thought-out process, based on the known facts and taking into account the geology, the history of the site and the amount of sample available and needed. We need to avoid sampling in different places and discard a motif if different areas need to be sampled. Ethics should play a key role when sampling. Sampling involves destroying the art, even when taking microsamples: small samples that may not provide a result today may be datable in the future. So, it is necessary to make sure to sample only what the available techniques can date at this stage. Accurately pinpointing the relation between the sample and the event that needs to be dated is fundamental for all methods but especially for calcite and oxalate formations: a direct relation between the sample and a motif or individual technical gestures is vital to obtain a reliable result. Once the sample has been taken, it needs to be examined before the decontamination process begins to identify possible contaminations (fungal, bacterial for radiocarbon or detrital for U series) (Hoyos, 1993; Fortea, 2000; Scharebereiter-Gurtner et al., 2002; Valladas, 2003). If possible, multiple sampling must be done for radiocarbon, while a stratigraphic sequence is needed to prove a closed system in the case of U series for a single motif.

Regarding radiocarbon results, several types of issues have been identified. In the case of the Upper Palaeolithic dates, a quarter of the results are contradictory with the stylistic proposals: Upper Palaeolithic style motifs rendered a late Post-Palaeolithic date. For this reason, it is evident that more experimentation on preparing the samples is needed, since the results indicate that contamination impacts the result significantly. Inconsistent results are caused by the unpredictable and complex composition of the samples taken. It is also due to: a) the sampling method, over large areas if no chunks of charcoal are available. Because of this they are more susceptible to environmental contamination (Hedges et al., 1998) and have possibly been exposed to bacterial or microbiological colonies as proven in Altamira (Scharebereiter-Gurtner et al., 2002) and Candamo (Fortea, 2000); b) the different composition of the pigment as demonstrated in Tito Bustillo (Balbín-Behrmann et al., 2003) and Candamo (Fortea, 2000); and c) the possibility of repaintings. These problems require greater consistency in the sampling process and only taking samples that have a secure link to what actually needs to be dated. In the last few decades, numerous appraisals have drawn attention to the actual relationship between the two critical events –the so-called dead wood problem– the death of the tree and the execution of the drawing (Clottes, 1994; Pettitt and Bahn, 2003; Pettitt et al., 2003; Pettitt, 2008).

Out of the 20 humic fraction dates obtained for the Iberian Palaeolithic samples, only four are statistically equivalent to the carbon fraction, thus corroborating, as Valladas (2001) proposes, that the contamination of the sample is minimal. Two of them provided younger dates than the pure carbon fraction, indication that modern charcoal contamination was eliminated in the final process (Valladas and Clottes, 2003). Thirteen of them are older than the carbon fraction. Following Valladas, the most common situation should be the former case, and the least frequent the latter because it would indicate an excessive pretreatment. However, as we can see from the results, the latter case it is actually the most frequent, which makes us question the samples where the humic fraction has not been analysed. In general, Valladas's suggestion about the interpretation of these dates is followed by archaeologists and the dates that coincide with what is expected are not questioned. On the other hand, the ones that are incompatible with what is expected are re-examined and criticised. In our opinion, given the problems registered in the cases where both fractions were analysed, all of the dates should be fully scrutinised.

The necessity for a reporting protocol on radiocarbon dates for rock art has been formulated (Lorblanchet, 1995; Rowe, 2004; Pettitt, 2008) and should at least include: sampled depiction, areas, sampling technique, description, initial weight, used pretreatment –if it deviates or not from the standard process– pure charcoal mass, behaviour during pretreatment, lab number, error and $\delta^{13}C$. This report should be also published in the case of 'rejected' or 'failed' dates. If possible, several samples should be taken for one depiction to determine if any repainting or retouching was done to specific areas. However, it is not usual for drawings or paintings to contain enough charcoal for this.

An inter-comparative program has been suggested on several occasions with the idea of verifying the results with different protocols and studying the possibility of refining the most widespread one (Valladas et al., 2001). However, it has never been applied to samples from rock art because of the lack of samples big enough to split between laboratories. The only case in the Iberian Peninsula in which a similar approach has been followed is in the case of the dots in Candamo (Fortea, 2000, 2007; Pettitt and Bahn, 2003; Corchón et al., 2014), which provided three different chronologies.

In the case of oxalates, the main problem lies in the difficulty in defining the relation between the sample and the motif. Currently we lack dates that are unequivocally associated with the art. Also, the fact that post-Palaeolithic samples are generally more exposed to the elements –owing to their frequent location in rock-shelters– adds more variables to an already complicated system.

The U-series technique allowed dating to be expanded to a much larger number of depictions since calcite regrowth is frequent in karst environments. If properly conducted, the sampling does not damage the motif, but the relationship between the sample and the motif has to be accurately established. The potential problems of the method have been addressed in several publications (Hoffmann et al., 2016, 2018c, 2020; Pike et al., 2017), such as applying a very cautious detrital correction and discarding the dated samples that do not maintain a rigorous stratigraphic order, so as to avoid samples that might have experienced 'leaching'. The main disadvantage of the method is that it only provides an *ante quem* date, because of this it is, however, very useful to date ancient motifs in the different art traditions. However, if the date is close to the end of a specific tradition, it is less relevant to define the specific moment when the motif was created.

Archaeologists have to be aware of the advantages and disadvantages, the problems of each method, their validity and limits to choose the right one to date a specific sample: we have to be certain of the relationship between the event and the sample. The result must be critically analysed with all the data at hand and not just blindly accepted, even if it is the expected one. If the result is unexpected, different possibilities should be considered: our previous interpretation was wrong or a failure in the dating process. In the second case the entire dating process should be evaluated to contribute to improve the methods for dating rock art.

6. Conclusions: looking forward

The existing problems and results discussed in this paper may suggest little progress has been achieved since the start of numerical dating. However, through trial and error we have moved forward on the methods and now we can develop strategies to improve and pinpoint the specific areas that need to be dated.

For Palaeolithic art, a substantial record of dates is available and progress has been made. The early upper Palaeolithic record was largely undated and there is currently no data on different phases in that period. Through U-series dating, researchers have been able to prove that Neanderthals were the authors of the first, non-figurative, cave art. Through the application of both U-series and radiocarbon, it has been proven that caves possessed symbolic value throughout the Upper Palaeolithic and they were used by different cultures, probably with different purposes. Moreover, despite the small number of dated motifs, there is direct evidence that motifs in a ‘Palaeolithic style’ were also produced after 12,000 cal BP (Bueno et al., 2007). In the near future, the focus should be on dating figurative motifs that are considered Gravettian/Solutrean to better define when figurative art appeared, and whether there are any recognizable phases or if most of what we regard as Pre-Magdalenian art is the consequence of a single prolonged artistic tradition.

Levantine art is as yet completely undated with reliable radiometric methods. The origin is still very much debated (for a summary see Villaverde, 2012; Villaverde et al., 2012; Fernández, 2014;~~,~~ Bueno & Balbín, 2016; etc.) because of the absence of unquestionable portable evidence, and with potential dates largely reliant on oxalate crusts (as referenced before), questionable binding agents (Roldan et al., 2018) or superimpositions. Therefore, the debate on the origin is still unresolved. Schematic and Megalithic rock art have provided some interesting results. However, the low numbers of dates obtained do not allow a much more precise understanding of the phenomena, so stylistic dating by comparison with portable art and artefacts is still necessary. According to the direct dates, some depictions in both traditions would be present during the last phases of the Neolithic and continue during the Chalcolithic until the early/middle Bronze Age. In contrast, ~~in Mediterranean Iberia,~~ parallels in portable art suggest that schematic art and megalithic art were~~was~~ present from the early Neolithic (Martí and Hernández Perez, 1988; Alday et al. 2019; Bueno and Balbín, 2012; Utrilla et al., 2008; Villalobos et al., 2020).

It must also be borne in mind that rock art has been analysed in parallel to cultural technocomplexes and the framework we currently have, for both Palaeolithic and Post-Palaeolithic rock art, indicates that changes in the economic trends do not necessarily imply changes in the symbolic record.

Methodologically, the emphasis needs to be set on refining the radiocarbon methods by targeting the problems above. This can only be achieved through collaboration between dating experts and archaeologists. The impossibility of dating most of the art requires a combined approach using information from different proxies –well-dated portable art, stylistic analysis, results obtained from absolute methods– to develop a certain, unequivocal framework that at the beginning might be sparse but can be improved as new data is produced.

Advances in dating methods and protocols are necessary to better connect rock art with the chronologies and contexts in which it was produced, and address different issues: not only its origin and development, but also to explore the art as a mirror of social geography, cultural exchange, the mobility of populations and the reutilisation of symbolic elements.

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