# Manuscript Details

**Manuscript number** HUMEV_2018_236_R1

**Title** Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian

**Article type** Full Length Article

**Abstract**

Castell de Barberà, located in the Vallès-Penedès Basin (NE Iberian Peninsula), is one of the few European sites where pliopithecoids (Barberapithecus) and hominoids (cf. Dryopithecus) co-occur. The dating of this Miocene site has proven controversial. A latest Aragonian (MN7+8, ca. 11.88–11.18 Ma) age was long accepted by most authors, despite subsequent reports of hipparionin remains that signaled a Vallesian age. On the latter basis, Castell de Barberà was recently correlated to the early Vallesian (MN9, ca. 11.18–10.3 Ma) on tentative grounds. Uncertainties about the provenance of the Hippotherium material and the lack of magnetostratigraphic data precluded more accurate dating. After decades of inactivity, fieldwork was resumed in 2014–2015 at Castell de Barberà, including the original layer (CB-D) that in the past delivered most of the fossils. Here we report magnetostratigraphic results for the original outcrop and another nearby section. Our results indicate that CB-D is located in a normal polarity magnetozone at about midheight of a short (~20 m-thick) stratigraphic section. The composite magnetostratigraphic section (~50 m) has as many as four to six magnetozones. These multiple reversals, coupled with the in situ recovery of a Hippotherium humerus from CB-D in 2015, make it very unlikely the correlation of any of the sampled normal polarity magnetozones with the long normal polarity subchron C5n.2n (11.056–9.984 Ma), which is characteristic of the early Vallesian. Our results support instead a correlation of CB-D with C5r.1n (11.188–11.146 Ma), where the Aragonian/Vallesian boundary is situated, and therefore indicate an earliest Vallesian age of ~11.2 Ma for Castell de Barberà. Our results settle the longstanding debate about the Aragonian vs. Vallesian age of this site, which appears roughly coeval with the Creu de Conill 20 locality (11.18 Ma), where hipparionins are first recorded in the Vallès-Penedès Basin.

**Keywords** Hominoidea; Pliopithecoidea; Hippotherium; Late Miocene; Magnetostratigraphy; Paleomagnetism

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## Submission Files Included in this PDF

**File Name  [File Type]**

Cover letter.R1.pdf  [Cover Letter]

Response to reviewers.R1.docx  [Response to Reviewers (without Author Details)]

Text R1 with changes.docx  [Revised Manuscript with Changes Marked (without Author Details)]

Title page R1 with changes.docx  [Title Page (with Author Details)]

Text R1 clean.docx  [Manuscript (without Author Details)]

Figure 1.tif  [Figure]

Figure 2.tif  [Figure]

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Figure 4 R1.eps  [Figure]

Figure 5 R1.eps  [Figure]

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Figure 7 R1.tif  [Figure]

Table 1 R1 with changes.docx  [Table]

SOM R1.docx  [e-Component]

To view all the submission files, including those not included in the PDF, click on the manuscript title on your EVISE Homepage, then click 'Download zip file'.

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Dr. Mike Plavcan
Editor-in-Chief, *Journal of Human Evolution*

Dear Mike,

Please receive a revised version of manuscript HUMEV_2018_236 ("Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian") by Alba and coauthors, to be considered for publication in the *Journal of Human Evolution*.

We are thankful to the reviewers for their detailed and constructive input and have substantially revised the manuscritp accordingly. A detailed response to the reviewer comments (with emphasis on those instances in which we were not able to implement their suggestions) has been attached as a separate 'response to reviewers' file.

The submission consists of the revised title page, main text, and table files (all in Word format), as well as a newly added SOM file (also in Word) and seven figure files (of which one is new and three have been revised to some extent). The SOM includes a brief text, two new figures and a new table, all of which included in response to the reviewer comments. The main text, in turn, has been extensively edited (including the title) and, to some extent, reorganized and rewritten (with multiple additions to adequately address the reviewer comments).

We think that the revised version has significantly improved thanks to the reviewers' input and hope that you will find it suitable for publication. We look forward to hearing back from you at your earliest convenience.

All the best,

David M. Alba

**RESPONSE TO REVIEWERS**

Ref: HUMEV_2018_236

Title: Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian: End of the controversy

Journal: Journal of Human Evolution

**Editor-in-Chief**

Thank you very much for submitting your paper to the Journal of Human Evolution. I have now received comments from two reviewers as well as a recommendation of "revise" from the Associate Editor. All agree that this is a well-written and engaging piece that is highly suitable for the JHE, but that will need revision before acceptance.

Both reviewers have provided detailed comments with ample explanation, requiring little elaboration from me. As you will see, reviewer #1 (Roberts, who provides his review in an attached document, as well as an annotated version of the manuscript) is highly complementary of the piece, but questions the claimed certainty of the dating. Assuming that this is true (I am not a dating person, of course), I have to agree that you need to drop ": End of the Controversy" from the title and re-tool the text to address the uncertainties in the dates. The reviewer provides very helpful and detailed explanation of his reasoning and recommendations for revision.

Reviewer 2 likewise provides a series of detailed and helpful comments that should greatly clarify the text. Most of these are very straightforward, and include a lot of grammatical and usage comments, all of which are quite helpful. Apart from this, I have nothing on my own part at this point to add to the text. Please look over the reviews and revise appropriately. When I receive the revision, I will return it to the AE for a second round of reviews.

**We thank the reviewers for their comments, which we found constructive and helpful to improve the original manuscript. Below we provide detailed explanations as to how we addressed these comments and outline the changes introduced in the text, which are also marked in a tracked version of the revised manuscript. With regard to the title, we removed "End of the controversy" at the end as per editor and reviewer's request. However, note that the alluded controversy referred to the Aragonian vs. Vallesian dating of the site (as implicit from the title and more explicitly stated elsewhere in the original manuscript). We discuss at greater length below the more detailed criticisms by reviewer 1 with regard to the dating.**

**Reviewer 1 (Andrew P. Roberts)**

Please see attached review and annotated manuscript.

**First of all, we would like to thank the reviewer for his very thorough review of the manuscript and the multiple edits and suggestions provided. We will discuss first the comments kindly provided by the reviewer in the annotated manuscript, and subsequently the more detailed comments sent by him separately.**

**Annotated manuscript:**

**Most of the edits provided by the reviewer have been incorporated to the revised version without further discussion, even if in many instances they were largely stylistic; these changes are marked in the tracked version of the revised manuscript. We only comment below (using line numbers of the original manuscript) those instances in which we were unable, or considered inappropriate, to implement the reviewer's edits and suggestions, along with other instances that in our opinion required further clarification. Note that the list below appears very long (ca. 80 edits commented). However, the Editor should be aware that the reviewer provided ca. 550 edits to the original manuscript, implying that between 80 and 90% of them were incorporated as proposed. The remaining ones were rebutted, no longer applicable, or applied with some modifications (see below for further details). Please accept our apologies in advance if we inadvertently failed to incorporate any edit not discussed below—we would gladly do so after the next round of review.**

**L14, 338, 422, 427, 431, 433, 507: the reviewer suggests to use "ca" instead of "ca." as an abbreviation of "circa". Both options are acceptable, but the latter has been maintained as per the journal's style.**

**L23, 597: the reviewer suggests to underline "in situ". Indeed, this is an English word (even directly taken from Latin) that needs not be italicized (e.g., see New Oxford American Dictionary). In any case, the journal's style does not allow italics except for genus and species names anyway ("words of Latin origin that are not abbreviated should not be italicized either" according to the Guide for Authors), so we could not implement this edit.**

**L30: the reviewer suggests to change "site of Creu de Conill 20" into "Creu de Conill 20 site". This was implemented, except that "locality" was used instead of "site", since Creu de Conill 20 is best considered one among various localities of the Creu de Conill site.**

**L41, 56, 60, 125, 127, 141, 142, 150, 156, 159, 173, 185, 213, 215, 225, 275, 278, 279: the reviewer suggests to add a hyphen in "Crusafont Pairó" and other composite surnames, but this is at odds with the criterion followed in the manuscript to spell the surnames**

**of authors as originally stated in their publications, even if they were not consistent in this regard (see also the response to reviewer 2 in this regard below).**

**L46-47, 182, 214, 321: the reviewer suggests to add a space between "author" and "#", but this is irrelevant as these expressions are only used to anonymize the manuscript for the purposes of double-blind review, and will be substituted by actual authors' initials upon final submission if the manuscript is eventually accepted. We prefer to keep these expressions as in the original manuscript so as not to overlook them when providing the definitive version of the file with authors' details at a later stage.**

**L81: the reviewer suggests to change "considered" into "consider". However, we prefer to maintain the past tense for all these sentences describing what previous authors published, in further agreement with "advocated" in the preceding line (not edited by the reviewer).**

**L86: the reviewer suggests to change "erected" into "proposed" regarding the new species described by Alba and Moyà-Solà (2012). We consider the former a frequent term in taxonomic contexts, but following the reviewer's concern we have substituted it by "described", which appears to us more suitable than the alternative proposed by the reviewer (except when the taxa are conditionally proposed, in which case they are not nomenclaturally valid according to the Code).**

**L91: the reviewer suggests to add "which is" but we prefer to add "which was", since we are referring to what Alba and Moyà-Solà (2012) did (see response to L81 edit above).**

**L138: the reviewer suggests to italicize "ad hoc", but this does not apply because of the same reasons as discussed above for "in situ" (response to L23 edit).**

**L139: the reviewer suggests to change "at odds with the very same definition of the Vallesian proposed by Crusafont himself" into "at odds with the same definition of the Vallesian proposed by Crusafont". Changed into "at odds with the original definition of the Vallesian proposed by Crusafont" not to alter our original intended meaning.**

**L154: the reviewer suggests to change "would have been washed down" into "was washed down". Changed into "was purportedly washed down" in order to highlight the uncertainty in this regard.**

**L222-223: the reviewer questions the need to capitalize "Alluvial Fan System" after "Castellar del Vallès" and "Upper Continental Complexes" by remarking "Are these formal names? If not, do not capitalize". In the revised version we have used lowercase because these terms are not formally defined in the sense alluded by the reviewer (however, we added three citations, including a new reference, where these complexes and alluvial fan systems are described in greater detail).**

**L236: we are unsure about one of the edits provided by the reviewer, but anyway the sentence was rephrased following also the advice from reviewer 2.**

**L237-238: regarding our fragment "based on the assumption that there is no major fault located between the two sections", the reviewer comments "perhaps not ideal**

**considering likely lateral variation of alluvial fan environment". We agree, but uncertainties in the correlation because of this fact were already explicitly discussed later in the manuscript. In the revised version we have further specified that no direct correlation was possible because of dense vegetation cover (this was implicit from the fact that we had to use heavy machinery to expose the sections, but better to explicitly note it, given the reviewer's concern in this regard; see also our response to the following comment).**

**L242: the reviewer asserts "assumes also that lithology is laterally the same—which is less secure a conclusion that lack of faulting". We agree that is an added problem and we have explicitly noted it in the revised version. However, we disagree that this problem is potentially more serious than major faulting, for the latter might cause the two sections not to overlap at all, whereas this is unlikely to be the case due to local variations in accumulation rates, at least according to our experience in this and other areas of the basin with the same type of depositional setting. Indeed, in the previous version we already discussed this problem (L343), and concluded that "Given the close distance between the two sections, local differences in accumulation rates are negligible". The sentences added in the revised version to acknowledge this and the previous concerns by the reviewer read as follows: "Such correlation methodology is far from ideal, not only because it has to assume the lack of major faulting, but also because it does not take into account lateral changes in lithology and local accumulation rates. However, such an approach was unavoidable given the dense vegetation cover between the two sections and the impossibility to deforest the whole riverbank in between."**

**L252-253: The reviewer suggests to rephrase "applied up to complete demagnetization of the NRM" as "used until samples were completely demagnetized", but we prefer a wording more similar to our original ("applied up to complete demagnetization of the samples"; see also our response to comments by reviewer 2 in this regard). The reviewer also suggest to rephrase "or observation of unstable behavior caused by neoformation of magnetite upon heating" as "or to temperatures at which unstable behavior was caused by neoformation of magnetite upon heating", but we have rewritten it a bit differently ("or to temperatures at which acquisition of spurious magnetization caused unstable behavior").**

**L262: The reference suggested by the reviewer (Kirschvink, 1980) has been added where indicated. The reviewer further asserts "see Heslop & Roberts (2016a,b) for improved way to calculate error." In this study a large number of samples did not yield good demagnetization data at temperatures above 400 °C, as acquisition of spurious magnetization at high temperatures prevented us from observing a clean decay of the NRM. Thus, calculation of magnetic components was done by anchoring directions to the origin. The authors are aware that this procedure yields errors that lack statistical**

**significance. Resulting MAD values are shown in the newly added SOM Table S1, but were not used to asses the quality of the paleomagnetic directions. Quality assessment is based on visual inspection of demagnetization plots as explained in the revised text, which has been significantly expanded in this portion to give additional methodological details. Several demagnetization plots have been provided in a new figure for the main text.**

**L267: the reviewer suggests to add "from this temperature range" at the end of the sentence and adds "is this correct? Why not use PCA over this temperature range? If the ChRM is not directed to the origin see Heslop & Roberts (2016b) for a suitable way to assess the need (or not) to anchor solutions". We did use standard PCA to calculate directions. In the revised version we have rephrased this sentence and, as explained above, expanded the whole paragraph to be clearer in this regard.**

**L280: the reviewer suggests to change "revision of the material" into "re-evaluation of the material". This is not suitable within a taxonomic framework, so we changed it into "taxonomic revision of the material" to be more specific.**

**L290: the reviewer suggests to change "during a recent revision of the collections" into "in our re-evaluation". With all due respect, collections are not re-evaluated, but revised, re-examined or restudied. We changed it into "in our recent re-examination of the large mammal collections", because it is relevant to specify that this is not the same as the taxonomic revision of the rodent remains alluded above.**

**L300: the reviewer suggests to change "broken in several fragments" into "broken into several fragments". However, this was changed into "fragmentary" following the advice of reviewer 2.**

**L322: the reviewer suggests to delete the comma after "fossa", but that edit would change our original meaning, since "fossa" is the last word of a clarifying statement within commas, and the referent for the "that" that follows is not "fossa" but "deep groove" in the preceding line. In any case we have rephrased the sentence to be more clear-cut.**

**L359: the reviewer comments "magnetostratigraphy is a binary signal so independent constraints are critical". We obviously agree, but are unsure as to whether the reviewer is requesting any changes in this passage. To be more clear-cut, we added a sentence to explicitly highlight the point raised by the reviewer: "This is because paleomagnetism only provides a binary signal, whose interpretation critically relies on independent constraints".**

**L361: the reviewer suggests to change "being mostly based on rodents" into "and is mostly based on rodents". We do not particularly like this alternative and rephrased it differently by providing such information earlier in the sentence and by further taking into account the suggestions by reviewer 2 in this regard ("largely" instead of "mostly").**

**L364: the reviewer suggests to change "changes in the rodent faunas" into "rodent faunal changes". However, the latter expression sounds a little weird to us and we think it is not customarily employed in the paleontological literature, so we did not implement this suggestion.**

**L369-370: the same as above applies to this reviewer's suggestion to change "datum provided by the rodent assemblage" by "rodent assemblage datum". We appreciate the reviewer's efforts to condense our original text as much as possible, and we generally followed his suggestions, but this should not be at the expense of intelligibility. We consider the reviewer's suggestion would alter our intended meaning and changed it into "datum provided by rodents".**

**L371: the reviewer suggests to change "and thus" into "which", but that would imply a second order subordinate sentence, both beginning with "which" ("...which precludes a correlation with the *Cricetulodon hartenbergeri* range subzone (MN9, 10.3-9.98 Ma), which indicates conclusively..."). We preferred to simply delete the comma and "thus", i.e., "which precludes [...] and indicates...".**

**L376 (and others): the reviewer suggests to abbreviate "Castell de Barberà" into "CB", but the use of the abbreviation throughout the manuscript was dropped following the alternate advice by reviewer 2 (see later in this document).**

**L378: the reviewer suggests to change "even if tentatively" into "which is tentative", but this changes our intended meaning, because we were referring to what Casanovas-Vilar et al. did, not asserting that in our current opinion the correlation is tentative. To be more clear-cut in this regard, we changed it into "even if they did so tentatively".**

**L380: the reviewer suggests to change "the find of *Hippotherium* remains at CB was" into "the *Hippotherium* remains at CB were", but we prefer "the record of *Hippotherium* at Castell de Barberà was".**

**L381: the reviewer suggests to change "dismissed" into "dismiss", but as explained above it is preferable to use past tense to describe what previous authors did or said.**

**L415: the reviewer suggests to change "to ascertain" into "discrimination of" when referring to the derived distinguishing features of *Hippotherium primigenium*. However, this change does not seem advisable in this context, because the problem is that available remains do not preserve the relevant anatomical regions. We therefore changed it into "to assess".**

**L416: the reviewer suggests to change "a very elongate" into "an elongated" in reference to the preorbital fossa of *Hippotherium primigenium*. However, this refers to the diagnostic criteria provided in the paper cited in this sentence: Bernor et al. (1996, p. 316) used the expression "very elongate" when referring to this anatomical structure. From a taxonomical viewpoint, the difference between "elongate" and "very elongate" is relevant, even if expressed qualitatively instead of quantitatively. Note as well that Bernor et al., like our original sentence, used "elongate" instead of "elongated". Both**

spellings are correct and have indeed slightly different meanings (e.g., see New Oxford American Dictionary): “elongate” means “long in relation to width” (and has no evolutionary implications), whereas “elongated” means “unusually long in relation to its width” (and might further be interpreted as indicating an evolutionary polarity, which is no implicit in “elongate”). Given these problems, we maintained our original wording.

L441: the reviewer suggests to place “therefore” between commas, but we prefer to move it to the beginning of the sentence (“Therefore, …”).

L447: we accepted all of the reviewer’s edits in this line, but added “this reasoning” between “and” and “has been”, because otherwise the sentence was ambiguous.

L459-460: The reviewer asserts “You need to show the stratigraphy between the sections to convince readers. You are asking readers to take a lot by faith”. We disagree from the latter assertion, as our rationale to perform the correlation is explicitly stated. In any case, in the revised version we have more explicitly recognized the limitations of this approach and further reported the stratigraphy in greater detail (see more detailed comments below). Note, however, that the latter has only been possible regarding the two studied sections, which were exposed by us with a digger machine. As explained above (and also in the revised version), it is not possible to expose the Miocene sediments located between the two sampled sections, which extend a few hundreds of meters along the riverbank (which, by the way, happens to be located within a riverine park that is densely frequented by the local inhabitants). We could not afford it financially and we would have never gotten the permits from the Catalan government and from the land owner (the city council). Therefore, we are not asking readers to take a faith leap, we are merely trying to report and interpret our results as honestly as possible. We acknowledge they might be suboptimal in some regards, and are willing to openly and explicitly note the limitations of our study in the manuscript, but the reviewer should be more understanding about the existing constraints, particularly since our paper reports the first magnetostratigraphic results for this site ever. Nevertheless, in response to the reviewer’s concerns, in the revised version we have provided more details (including a new supplementary figure) about the stratigraphy (see also our response later in this document to the more detailed comment by the reviewer in this regard).

L470-472: the reviewer asserts “OK – but since time is short & sedimentations rates are high, you could be reading polarity manifestations of tiny wiggles”. In the revised version, this possibility suggested by the reviewer has been explicitly discussed (see further details below in response to the more detailed comments provided by the reviewer).

**L471: the reviewer suggests to add "lower" before "sampled normal magnetozones", but this is unnecessary since the fact that the uppermost part of the sample sequence is excluded was already noted later within the same sentence.**

**L488-490: the reviewer asserts "this text is not perfectly clear—please improve". We agree that this sentence was unnecessarily complicated and indeed it had a few mistakes that hindered interpretation. In the revised version we have deleted and rephrased this portion of the paragraph to be more clear-cut.**

**L503: the reviewer asserts "not really – see separate comments", in allusion to our sentence excluding correlation with the long normal chron that is characteristic of the earliest Vallesian. This relates to the above-mentioned tiny wiggles, and has been replied in greater detail later in this document.**

**L507: the reviewer asserts "I am not sure you can resolve to within 100 kyr in these sediments". We disagree, previous magnetostratigraphic work at the Vallès-Penedès Basin indicates that this is possible, particularly for time intervals where multiple reversals occur over a short time span, as it is the case of the earliest Vallesian. Previous work in similar depositional settings from the late Aragonian of the same basin further suggests that magnetostratigraphically interpolated dates are accurate to the nearest 0.1 Ma (see Alba et al., 2017, for a more elaborate reasoning). All in all, we consider sufficient to explicitly discuss the additional sources of uncertainty (the tiny wiggles) noted by the reviewer above, and refrain from further modifying this sentence, which merely explains that we did not favor this particular correlation because it would imply an earlier record of *Hippotherium* than elsewhere.**

**L509: the reviewer suggests changing "representing" by "which represents", but that would change our intended meaning, for "which" would refer to Creu de Conill 20 only, whereas we referred to both Castell de Barberà and Creu de Conill 20. It has been changed into "and both sites would represent"**

**L531: the reviewer suggests to change "castorids" into "castorid rodents" because he deleted "As far as rodents are concerned" from the beginning of the sentence. Although we adopted the latter change, specifying that castorids are rodents is not really necessary.**

**L535: the reviewer suggests to change "overall indicating" by "which overall indicate", but this would change our intended meaning by restricting the subordinate sentence to *Chalicomys* instead of both *Euroxenomys* and *Chalicomys*. We therefore opted to make a new sentence: "These taxa indicate…".**

**L536: the reviewer suggests to change "permanent water bodies at the area of the site" into "permanent water bodies at the site", but the latter is too restrictive, as we are unsure whether these water bodies were located exactly at the location of the site or somewhere nearby. We have changed it into "permanent water bodies nearby".**

**L554: the reviewer suggests to change "remains of *Euroxenomys minutus*" into "*Euroxenomys minutus* remains". While the use of genus names as adjectivated nouns is very frequent (e.g., *Euroxenomys* remains) and we have adopted all of the reviewer's suggestions in this regard, the use of species binomina as adjectivated nouns in written form is generally advised against. Therefore, we have not implemented this suggestion.**

**L561: the reviewer suggests to change "provide an accurate dating" into "provide accurate dating", but this fragment was changed instead into "provide an accurate date" as per reviewer's 2 request. Reviewer 1 further adds: "see my separate comments about chronology". Our response to such comments is provided later in this document.**

**L597-602: the reviewer asserts "I am not convinced" regarding our preferred magnetostratigraphic correlation. This has already been discussed above and more detailed responses are given below. After explicitly discussing in the revised version alternate possibilities put forward by the reviewer, we feel there is nothing much that we can do to be more convincing. We hope to have openly discussed the pros and cons of the various possibilities, and acknowledge that the reviewer comments have been most useful in this regard, but invoke our right to explicitly favor the interpretation that in our opinion is more likely in the light of currently available data. The revised version is more explicit in this regard.**

**L606: the two last edits provided by this reviewer in this line no longer apply after rephrasing of the sentence following the suggestions by reviewer 2.**

**L995-997 (caption of Fig. 5): the reviewer asserts "c, s, & l for lithology? Please spell out. What is the meaning of black circles & white circles for paleomagnetic data? Presumably sideways triangles on the strat columns indicate sampling horizons – please specify this in the caption". This has been explained in the revised version, please see below for more detailed explanations as this comment was also provided separately by the reviewer.**

**With regard to the reviewer's more detailed comments, we have copied them below in order to provide a response.**

This is a clearly articulated and beautifully written paper that claims to lay to rest debates about the age of fossil finds at the Castel de Barberà (CB) location in Catalonia. I found the paper so convincing as I read it that I did not start to worry about the final result until the punchline arrived. I expected to provide a more positive evaluation than the one below. The sense is given in various places that a magnetostratigraphy provides an unambiguous age for these deposits even though the authors acknowledge that different interpretations of the polarity zonation are possible. Geomagnetic polarity is a binary signal, so independent age constraints are usually needed to tie down a set of identified polarity zones that are otherwise "floating" in time. The authors obviously understand this and argue that a clear

interpretation is still possible. I am not convinced, as argued below. At minimum, further information needs to be presented to make the case more rigorously and convincingly, but I argue below that there are ambiguities in this part of the timescale that may make the issue difficult to finally resolve with the level of certainty claimed by the authors. I have annotated the manuscript to help the authors to improve or condense the writing. Many of my annotated comments are not reproduced below, so careful attention to both will be needed. The results presented are valuable and deserve to be published in the *Journal of Human Evolution*. My reservations relate to the final chronological interpretation, which I think should be presented so that the ambiguities that I suggest below are recognized and discussed in the final interpretation.
**We appreciate the reviewer's constructive criticism, but as noted above we need to highlight that unambiguity of the correlation depends on whether we are talking about land mammal ages (Aragonian vs. Vallesian), (sub)chrons, or hundreds of ka. In our original manuscript, we did recognize that several correlations where possible, yielding slightly different ages, but based on biostratigraphic data we argued that a Vallesian age was most conclusive (as explained above, this is to what we alluded in the original title). We further provided arguments to favor one of the possible correlations with the earliest Vallesian, without omitting other possible correlations. We still adhere to our previous interpretation that the site can be securely correlated to the Vallesian (instead of the Aragonian, as previously favored by most authors) and that one of the discussed correlations is more likely to alternative ones. However, following the reviewer's concerns we have discussed in greater detail the various alternate possibilities. Below we provide more detailed responses in this regard.**

**1.** Even if the conclusions of the paper were totally sound, I would find statements such as "End of the controversy" in the title of the paper to be grandiose. It is better to let readers decide for themselves rather than to use hyperbole. I recommend removal of such statements (my annotations on the manuscript have done this).
**Done.**

**2.** The paleomagnetic results are presented a little too sparsely to enable rigorous assessment of data quality. It is usual to include a number of demagnetization diagrams with an assessment of the magnetic mineralogy responsible for the signal and brief discussion of the remanence acquisition mechanism to provide readers with the sense that this has been worked through carefully and that the reported signals are not due to remagnetizations of various types. This level of information is missing and should be added. This is what I refer to above as the minimum further information that should be added to strengthen the paper. My annotations on p. 11 are relevant to this issue, which include questions about how the characteristic remanent magnetization was determined and whether principal component analysis solutions were anchored or not to the origin of demagnetization plots.

**The reviewer annotations have already been commented above. In the revised version we have added the demagnetization diagrams requested by the reviewer as a new figure for the main text, which has also been expanded to provide additional details.**

**3.** In addition to the above, and while extensive effort has been made to present and justify the main paleontological finds, an equivalent level of care has not been made to illustrate the stratigraphic context of the CB site. With two locations sampled, arguments are made about lithological correlation and the dip of beds, including potential faulting — but with no lithostratigraphic correlation presented. I consider this to be a critical part of the story that needs to be documented and illustrated clearly in new figures in a way that convinces readers. Most readers, including myself, will not know the local lithological units and whether they are laterally extensive or not. From the description provided, alluvial fan environments would be expected to be highly variable laterally, with local channels and variable interbeds between fluvial gravels and finer-grained units. I am left wondering how the two sampled locations might relate to each other in such a context. It may be that these concerns are not important, but I would like to be convinced of this. It is a fundamentally important issue for the chronological interpretation. I thought the discussion of possible and undocumented faulting is less important than this issue. Likewise, I would have thought that the potential for erosion of underlying strata by migrating river channels could also be important. Without a clear diagram that illustrates the stratigraphic context, stratal dip, and elevation and lithological differences between the sampled sites, the authors are asking readers to take a lot by faith. The authors do a good job of demonstrating that past work has not been adequate for various reasons, which makes it reasonable to request full documentation of site stratigraphy and inter-site lithological correlation.

**As per reviewer's request, in the revised version we have added a supplementary figure with the two lithostratigraphic profiles and their suggested correlation. However, as explained above, the reviewer should be aware that the whole area is densely covered by vegetation, and that the two sections studied had to be dug with heavy machinery in order to be exposed. This severely limits the possibility to directly assess the correlation between the two sections, which are nevertheless quite close to one another. Extensive exposures in other areas of the basin (Abocador de Can Mata) with a comparable depositional context have shown that most stratigraphic levels have a high lateral continuity (see Alba et al., 2017, cited in the ms.). This has been briefly discussed in the revised version.**

**4.** While the above issues are important, my main comment on this paper concerns the polarity interpretation. When dealing with the binary geomagnetic polarity signal, it is nice to have a long polarity interval that can be excluded for correlation because more frequent reversals do not fit with such a pattern. Thus, interpretation of the late Aragonian and early Vallesian seems to be a cast-iron case for such a situation … but it is not. The authors have plotted the locations of three "cryptochrons" in the long normal polarity Chron C5n.2n. The origin of cryptochrons is indicated in their name —they are cryptic. The Cenozoic polarity timescale is based on the polarity pattern observed in marine magnetic anomalies (see Cande and Kent (1992a; *JGR*) on the GPTS). The resolution of the marine magnetic anomaly record is limited by the smallest resolvable anomalies, which are referred to as 'tiny wiggles' (see Cande and Kent (1992b; *JGR*) on 'tiny wiggles'). These small anomalies with durations <30 kyr are referred to as cryptochrons because their origin is less clear. Three origins have been proposed in the literature for cryptochrons, where they could represent: (1) short-duration polarity zones; (2) shorter geomagnetic excursions (typically a few kyr in duration); and (3) largescale changes in geomagnetic dipole field intensity without an accompanying field reversal. Relatively little work has been done on the origin of tiny wiggles. I have suggested that detailed magnetostratigraphy of rapidly deposited sediments is the best way to test these alternatives (Roberts and Lewin-Harris, 2000; *EPSL*), and provided a direct magnetostratigraphic test of the origin of tiny wiggles in the same time interval of relevance to the present study, Chron C5n.2n, and concluded that some are likely to represent short polarity chrons and some probably represent geomagnetic excursions. This interpretation has been contested, but it is not unique. Several papers that I cited in 2000 reached similar conclusions for Chron C5n.2n and more have probably been produced in the succeeding years (Garcés et al., 1996; Li et al., 1997; Rössler and Appel, 1998; Roperch et al., 1999). Garcés et al. (1996) studied sediments of this age in the Vallès-Penedès Basin, as cited in the reference list, so this possible interpretation must be known by the authors and has been dismissed without discussion. My difficulty in accepting the proposed interpretation is that the time represented by the CB section is short and sedimentation rates are high, so the sediments could easily be recording short polarity intervals or geomagnetic excursions associated with the "tiny wiggles" in Chron C5n.2n. All of this adds ambiguity rather than clarity to the interpretation, which makes me sceptical of the authors' claims that they can resolve the chronology of the CB section to within 100 kyr. I wish it were so, but I am not convinced. I am not sure that this issue is resolvable. I think it represents an ambiguity that must be considered when working with this part of the timescale in rapidly deposited sequences. I think the best way to deal with this is honestly by recognising that additional magnetostratigraphic interpretations are possible and that the CB location cannot be dated with the precision stated with the information presented.

**We thank the reviewer for such detailed explanations, but we feel that, while doing so, he is overemphasizing the likelihood of alternate interpretations based on the tiny wiggles (which, after all, would equally imply a Vallesian age for Castell de Barberà!). We acknowledge that we might have been too categorical in some portions of the manuscript,**

**such as for example the Abstract, where due to space constraints we did not mention other possible correlations. The revised version has been modified accordingly to be more explicit in such places about other alternate correlations, but it needs to be stressed that in the original version we already discussed several alternatives. For example, in the Discussion: L457-462: "The magnetostratigraphic data reported in this paper further enable a more accurate dating of CB within the early Vallesian, even if the shortness of the sampled sections allow for several possible interpretations. The most parsimonious interpretation, based exclusively on stratigraphic distance between the two sections as computed from dip measurements, implies as much as six different magnetozones. Other interpretations imply four to five different magnetozones." We continued to argue that even under alternate correlations, the sampled sections were unlikely to represent more than 400 kyr, so that it was possible to exclude a correlation with C5n.2n. The reviewer's criticism above does not apply to the need to recognize different possible correlations between the two sampled sections (which we already did), but rather only refers to our dismissal of a correlation with C5n.2n, which the reviewer think is feasible due to the existence of various cryptochrons. In the revised version, we adhere to our former preferred interpretation . However, instead of dismissing an alternate correlation with C5n.2n without further consideration, we have rephrased the relevant paragraph and added a new paragraph below to explicitly discuss such possibility and explain the reasons why we consider it unlikely. This has required adding some references. The new paragraph introduced in the revised version is reproduced below in italics:**

***An alternate correlation of the reversed polarity magnetozones R2 and R3 with some cryptochrons or geomagnetic excursions within C5n.2n (Cande and Kent, 1992; Roberts and Lewin-Harris, 2000; Evans et al., 2007) is considered unlikely because of the short duration, possibly less than 10 kyr, of these events. While chances of recording such short geomagnetic features in fluvial sediments are typically low, to record as many reversed polarity directions as normal polarity directions within C5n.2n is considered implausible. The fact that all the reversed polarity magnetozones documented at Castell de Barberà are recorded by more than a single paleomagnetic sample strongly argues against any of them representing a short-lived excursion event within C5n.2n. The similar thickness of the documented normal and reversed polarity magnetozones at Castell de Barberà strongly argues against this possibility, and favor a correlation of most of the sequence with chron C5r.***

**Further details about 'tiny wiggles' have been added to the caption of former Fig. 6, which has been partly redrawn to add the 'excursion chrons' identified by Evans et al. (2007). We have further rewritten a bit several sentences of the abstract to be less categorical about the age while making it clear that the controversy that we consider settled is that of the Aragonian vs. Vallesian age of the site.**

**5.** Various minor information additions are needed for the figure captions. For Figure 2, please state which section was excavated. For Figure 5, please add descriptions for the c, s, and l lithological abbreviations. Also, please spell out the meaning of the black and white circles for paleomagnetic data. Presumably the sideways triangles on the stratigraphic column indicate sampling horizons — please specify this in the caption.
**We assume that the reviewer refers to panel B in Figure 2, which read as "Detail of CB during the excavation of layer D [...]"; earlier in the caption, we defined CB as "the classical site of CB", so we thought it was clear (at least looking at panel A) that CB corresponds to Section 2. Nevertheless, following the reviewer's request we specified the section for the sake of clarity.**
**With regard to Figure 5, we added the lithological abbreviations that were inadvertently omitted in the previous version (c = conglomerates; s = sandstones; l = lutites). We also specified the meaning of triangles and white circles in the caption of this figure.**

**Reviewer 2**

There are a lot of comments here, but most are quite minor and I think can be addressed without too much difficulty. I enjoyed reading this paper. In my opinion the work is suitable in quality and scope for the journal, and makes an important contribution to our understanding of an interesting catarrhine-bearing fossil site.
**We thank the reviewer for the positive overall evaluation and the constructive criticism, see below for more detailed responses.**

<u>Major Comments:</u>

There are some issues with the chronostratigraphic terminology being used in this manuscript. The 'Aragonian' is not a commonly understood term outside of Iberian Peninsula paleontology, and absolutely needs some explanation and justification for this audience. For this journal, it really might be better to stick to the recognized continent-wide ELMA bins (so Astaracian instead of Aragonian). Even better than that would be to employ the ICS (International Commission on Stratigraphy) names, which are the most widely recognized. Part of my concern is that the Aragonian covers such a long span of time, so it ends up being a rather less specific term than other, contemporary units that are the same age as the 'late Aragonian'. Of course, I understand that the Aragonian does have a particular meaning, and that you may prefer to use it here, at least some of the time. In that case you must properly cite its origin, the precise meaning, and its specific relationship to these other better-known terms. I found the explanation in Steininger 1999 (p. 11) quite helpful. A brief explanation (like that by Steininger) explaining that the term was coined by Daams et al., and is generally used only in southwest Europe, would help. It's worth noting that the legend in Figure 3 uses the ICS names, so you need to at minimum clarify the relationship between those terms and the terms you use in the text. Also, line 116 introduces the term Vindobonian – is this strictly necessary? If so, then again, it needs explanation.

**We know that the Aragonian is not generally used outside the Iberian Peninsula, but this is because the former has been defined as a regional unit restricted to Spain. In contrast, the Astaracian is not used in Iberia and to our knowledge it has not been formally defined anywhere (unlike the Aragonian). We have been using the latter term for many years in many publications without encountering any opposition from reviewers, so when preparing the original submission we did not even consider the need to provide further explanations. Following the reviewer's concerns in this regard, we have clarified the meaning of the Aragonian and our reasons to favor this term (as well as the use of land mammal ages more generally), since our views clearly differ from those exposed in the reference cited by the reviewer (Steininger, 1999), whose alternate proposal is not exempt of problems. Given that a large portion of the readership of the journal will not be familiar with the controversies surrounding the Aragonian and other European land mammal ages, in the revised version we have not restricted ourselves to a short clarifying statement and have provided a new subsection of the Introduction (1.2. Vallesian and Aragonian European land mammal ages), with most of the text from former subsection 1.2 (The controversial age of Castell de Barberà) renumbered as 1.3. The reviewer's concerns in this regard have made us realize that insufficient background was provided in the original version regarding these terms, which are central to the discussion, since our manuscript aims to resolve the longstanding controversy of whether Castell de Barberà is Aragonian or Vallesian in age. We therefore think that this is a welcome addition with regard to the international readership of the journal, most of which will not be familiar enough with these terms and even with the controversies and problems associated with the definition of land mammal ages (as rightly pointed out by the reviewer). Nevertheless, we remain open to editorial suggestions regarding the need to shorten this new passage after the next round of review. The added fragment has been reproduced below in italics:**

***[...] has been hampered by a longstanding controversy about the age of this site—including whether it correlates to the Aragonian or with the Vallesian European land mammal ages (ELMAs). Some clarification is required with regard to the concept of ELMAs (for a historical review, see Lindsay and Tedford, 1990 and Van Dam, 2003), with particular emphasis on the use of 'Aragonian' instead of Orleanian + Astaracian, despite the latter are more widely used outside Spain. The use of ELMAs as geochronological units has been criticized (e.g., Steininger, 1999) on the grounds that they are regional and that, with few exceptions, they do not correspond to properly defined chronostratigraphic units (stages). 'Mammal ages' are generally conceptualized as "biochronologic units" (e.g.,***

*Woodburne, 2004a: xiv; see also Hilgen et al., 2012) of regional applicability due to divergent paleobiogeographic histories among regions (Lindsay and Tedford, 1990). However, an initial definition of land mammal ages as biochronologic units (i.e., biozones) is not mutually exclusive with their subsequent formal definition (based on bio- and magnetostratigraphic data) as chronostratigraphic units (i.e., stages, based on bodies of rock formed during a given time interval; e.g., Garcés, 1995; Woodburne, 2004), which automatically implies the definition of their corresponding geochronologic units (ages). The definition of regional chronostratigraphic units is not at odds with the International Stratigraphic Guide, because "It is better to refer strata to local or regional units with accuracy and precision rather than to strain beyond the current limits of time correlation in assigning these strata to units of a global scale" (Murphy and Salvador, 1999:267). Even if not directly correlated with marine stages, regional continental units can be dated based on radiometric and/or paleomagnetic methods (e.g., Krijgsman et al., 1994; Garcés et al., 1996). Steininger (1999) conversely advocated abandoning a chronostratigraphic/geochronologic concept of ELMAs altogether and proposed to replace them by entirely biostratigraphic units ('European land mammal mega-zones') based on MN (Mammal Neogene) biozones (Mein, 1975). This proposal is not exempt of problems given that MN zones were defined as informal biochronologic units (Mein, 1975) and that their utility at a continental-wide scale is restricted due to the significant diachrony of most mammal biochronologic events (van der Meulen et al., 2011, 2012). This has led some authors to contend that a formal European biozonation is not possible (van der Meulen et al., 2012), which would imply that the regional nature of formally defined ELMAs such as the Aragonian (see review in van der Meulen et al., 2012) would rather be an advantage with regard to providing accurate correlations.*

*The lack of formal (biostratigraphic and chronostratigraphic) definition of widely used biochronological units such as Orleanian and Astaracian is a problem that does not apply to the roughly time-equivalent Aragonian, since like the younger Vallesian (which enjoys a wider geographic applicability) it has been formally defined on the basis of a specific stratotype. Crusafont Pairó (1950, 1951, 1953, 1955; see also Crusafont Pairó and Truyols Santonja, 1954, 1959) first used the term Vallesian in a largely biochronological sense to designate the Vallès-Penedès deposits with* Hipparion *(currently* Hippotherium*) that, based on the fauna, appeared intermediate in age between the sites of La Grive in France (i.e., the Aragonian) and Pikermi in Greece (i.e., the Turolian). The Vallesian was finally more formally defined in reference to Vallès-Penedès mammal successions by Crusafont Pairó and Truyols Santonja (1960) based on the entry of* Hippotherium *as its main defining criterion. The Vallesian was rapidly accepted throughout Eurasia as a simple solution for the complex stratigraphic terminology in use, although it was not until decades later that it was formally defined as a 'mammal stage' based on a specific stratotype from the type area (the Vallès-Penedès Basin) within an accurate bio- and magnetostratigraphic*

***framework (Garcés, 1995; Garcés et al., 1996; Agustí et al., 1997). Following the proposal of MN zones by Mein (1975), MN9 and MN10 had already been equated with the early and late Vallesian, respectively, in turn subdivided into multiple local biozones based on rodents (Agustí, 1981, 1982; Agustí and Moyà-Solà, 1991; Agustí et al., 1997; Casanovas-Vilar et al., 2011a, 2016b).***

***The Aragonian was in turn originally conceptualized (Falhbusch, 1976) as a chronostratigraphic unit defined by the presence of the equid*** **Anchitherium** ***and the lack of the more derived equid*** **Hipparion** ***(currently*** **Hippotherium*****), and subdivided into two subunits, the Orleanian and the Astaracian. Soon thereafter, the Aragonian was defined by Daams et al. (1977) as a new stage for continental middle Miocene deposits preceding the Vallesian, with its stratotype located within the Calatayud-Montalbán Basin in Spain (see also Daams et al., 1999). However, Daams et al. (1977) refrained from dividing the Aragonian into Orleanian and Astaracian because the latter had yet to be formally defined, ultimately leading to a tripartite subdivision (Daams and Freudenthal, 1981; Daams and Freudenthal, 1990). Moreover, the original criterion used to define the base of the Aragonian (the dispersal of*** **Anchitherium*****) was soon questioned (Daams and Freudenthal, 1981) and eventually abandoned following the definition of the Ramblian stage (Daams et al., 1987; see also Daams and Freudenthal, 1990). Further stratigraphic refinements of the Aragonian were later provided by Daams et al. (1987, 1999) and van der Meulen et al. (2012), who further distinguished multiple Aragonian local biozones based on rodents. Based on these works, currently the Aragonian may be considered a regional mammal-based chronostratigraphic unit (stage), whose scope is limited to the continental record from Spain (see recent reviews in van der Meulen et al., 2012 and García-Paredes et al., 2016). Given the scope of this paper and the detailed local zonation of the Aragonian available for the Vallès-Penedès Basin (Casanovas-Vilar et al., 2016b), we refrain from using the alternative and more loosely-defined term 'Astaracian'.***

***Based on high-resolution magnetostratigraphic correlation to the geomagnetic polarity time scale (GPTS), according to Van der Meulen et al. (2012) the early Aragonian (ca. 17.2–15.9 Ma) corresponds to the late Burdigalian (early Miocene, MN4), while the middle Aragonian (ca. 15.9–13.8 Ma) comprises most of the Langhian (early to middle Miocene, MN5), and the late Aragonian (ca. 13.8–11.2 Ma, roughly equivalent to the 'Astaracian') covers the latest Langhian, the Serravallian, and the earliest Tortonian (middle to late Miocene, MN6 to MN7+8). The Vallesian, in turn, entirely corresponds to the Tortonian (late Miocene), being subdivided into early Vallesian (11.2–10.0 Ma, MN9) and late Vallesian (10.0–8.9 Ma, MN10; e.g., Hilgen et al., 2012; Casanovas-Vilar et al., 2016b).***

**With regard to other recommendations by the reviewer, as it is clear from the text above we still generally refrain from using the ICS stage names instead of the ELMAs, as the former are not customarily used in works dealing with continental sediments and fossil**

**sites. The only reason we used the latter terms in the legend of Figure 3 is because this figure is a geological map that further includes marine sediments. Nevertheless, as it can be shown in the fragment reproduced above, in the revised version we have specified the correlation of the Aragonian and Vallesian subdivisions with the ICS marine stage names. Finally, in the original manuscript the term Vindobonian was used only once (and within quotation marks) because we were referring to the works of previous authors that "advocated for a 'Vindobonian' (currently, late Aragonian) instead of Vallesian age for CB" (these authors did not employ the term Aragonian because it had not been defined yet). Following the reviewer's concern in this regard, in the revised version, we have simplified this sentence ("advocated for a pre-Vallesian age for CB") in order to avoid introducing unnecessary confusion because of this outdated term.**

Throughout the manuscript, three different names are being used to refer to your sections – section 1, section 's.l', and CB1; and section 2, section 's.s' and CB2. This seems unnecessarily complicated. If the problem is that previous publications or abstracts have used one name, and now you prefer another, then you need to just explain that. Then pick one name and stick with it throughout this manuscript. Personally, I like CB1 and CB2 – very simple and easy to understand. If you're going to use 'section 1' and 'section 2', then I would suggest treating these as proper nouns and capitalizing (Section 1 and Section 2). **Note that throughout the previous version of the manuscript we mostly used section 1 and section 2, and we prefer to keep these names for the sections, in order to avoid confusion with the nomenclature used for the corresponding fossil localities. Therefore, in the revised version we have followed the reviewer's suggestion to capitalize 'Section 1' and 'Section 2'. CB1 and CB2 were only used in former Figure 6, and this has been changed by 'Section 1' and 'Section 2' as well, since CB1 and CB2 resemble acronyms used for fossil localities in the Vallès-Penedès Basin. As for s.l. and s.s., these abbreviations were included to denote the equivalence of the sections with the fossil sites, and were only mentioned twice in the main text and also in Figures 5 (both image and caption) and 6 (only caption). We have omitted these terms from the figures, but we would like to keep them somewhere in the revised manuscript to clearly state the equivalences with the fossil sites (since these terms have been used in field reports and also in the collections of the institution where the material is curated). To be more clear-cut in this regard, we have added further explanation in the supplementary material of the revised manuscript.**

Your newly recovered *Hippotherium* humerus is said to come from level 'D', which is also said to be the same level that the material collected in the 1960s and 1970s comes from. But on line 197 you say that 'the main fossiliferous level' was exhausted and that the fossils collected came from somewhere else. Please clarify. Calling your fossil level 'layer D' also begs the question of what other fossiliferous layers you found. What were A, B, and C?! Are they worth explaining? Please note that you also use both the terms ‘layer D’ and ‘level D’; you should use one, and it would also probably be helpful to treat it as a proper noun as well – Level/Layer D.

**The exact quote from the previous version of the manuscript alluded by the reviewer is “our works confirmed that the bone accumulation of main fossiliferous level of CB is exhausted”. Therefore, we did not assert that the main fossiliferous layer was exhausted, only that the bone accumulation of this layer was so. This might seem a trivial distinction but it explains the apparent incongruence noted by the reviewer. Isolated fossil finds occur throughout the section, including this very same layer. To be more clear-cut in this regard, to our former fragment “enabled the recovery of additional fossil remains” (now modified as “we recovered additional fossils remains”, following the edits by reviewer 1) we have added “from the same layer and other layers”. As asserted above, in the supplementary material we have clarified how the various fossiliferous layers (or localities) within each site were termed, and have further referred to a new supplementary figure in which we report the stratigraphy in further detail (including the name of the various layers). The uppercase letters alluded by the reviewer denote different fossil localities within each site. Besides layer D, in the footnote to Table 1 we explained that layer B was situated 2 m below D and that E was located 1 m above D. However, we agree that further explanation is required. The new supplementary information that we have added in this regard clarify all these questions.**

**The terms ‘level’ and ‘layer’ were used interchangeably as synonyms in the previous version. In the revised version, we have favored the use of the latter term. We did not capitalize this term when followed by an uppercase letter denoting a particular layer (e.g., Layer D), as suggested by the reviewer, because this expression has been substituted by CB-D in the revised manuscript.**

I think the Materials and Methods section needs some reorganization. I’d suggest having some introductory material that explains the site location, section locations, and basic stratigraphy first, then separate sections (2.1 and 2.2) to explain the methods for biochronology and paleomag. I would think that it would make more sense to explain the paleomag methods first, and then the biochronology (particularly because as written, line 205 sounds like it should come after the section on paleomag). The entire first paragraph of this section (lines 205-220) would be clearer if it were reorganized – location of site, then basic stratigraphy before trying to make the argument that you can know that your layer D is the same as the original layer.

**We have reorganized the Materials and methods section following the suggestions by the reviewer. Note, however, that the paragraph of L205-220 includes the portion about biostratigraphy that the reviewer requests to move after the paleomag methods. Therefore, only the sentences from L205-209 were moved there, whereas the rest of the**

**paragraph (L209-220) was kept in the first subsection but moved after the paragraph indicating the geological background and depositional setting of the site as known from the previous literature. The new paragraph that explains the stratigraphy and the definition of fossil localities (see above) was added to the end of the first subsection. To sum up, in the revised version the Materials and methods are divided into subsections 2.1 ("Location and stratigraphy of Castell de Barberà") and 2.2 ("Paleomagnetism and biostratigraphy"). Note that in this particular context we prefer the term 'biostratigraphy' rather than that of 'biochronology' (as suggested by the reviewer), given that we are using the fauna to discuss the dating of the sediments, instead of discussing the correlation between different bioevents.**

Despite your assertions that 'most' of the original material came from a single layer (line 213), there really does seem to be legitimate reasons for uncertainty as to the provenance of the original *Hippotherium* material (e.g. the existence of 'layer 1' and 'higher layer'). Assuming that we really cannot know where those two specific dental specimens came from, your argument really rests largely on your new humerus. Given that, I would suggest adding a comparative photo of an anchitheriine equid to Figure 4 so that the reader can clearly see the two anatomical differences you describe. Trochlea height should be fairly obvious to any informed reader, but the origin of the extensor digitorum communis muscle should perhaps be highlighted with an arrow or dashed line so that it is clear. Note that you refer to this feature as both a 'groove' (line 321) and a 'crest' (line 325), which should be clarified.

**In the original version we described the structure alluded by the reviewer as (L321-322) "a narrow but deep groove, medial to the lateral epicondyle and separated by the lateral surface of the radial fossa". In the revised version, we have provided a new version of former Figure 4 with better photographs of the Castell de Barberà specimen (after reintegrating various fragments). The use of 'crest' instead of 'groove' was an inadvertent mistake that has been corrected in the revised version, which by the way has been rephrased at this passage to be more clear. With regard to the addition of an anchitheriine humerus, we have added a new supplementary figure in which the distal articular morphology of Castell de Barberà distal is compared with that of *Anchitherium*. An arrow has been added in the former specimen to denote the localition of the discussed anatomical structure.**

**Even though we agree that the reviewer's suggestions for this figure represent a welcome addition, with regard to the reviewer's comment as a whole we would like to stress that, in the previous manuscript, we did explicitly recognize the uncertainties about the exact stratigraphic provenance of the *Hippotherium* material from the classical collections, but never intended to question their provenance from Castell de Barberà (as the reviewer seems to imply). We further disagree to some extent with the reviewer's assertion that**

**“your argument really rests largely on your new humerus”. This new specimen certainly makes the discussion about the provenance of the previous finds rather irrelevant, but as we already highlighted in the original version (L385-388) “Even if both teeth came from a stratigraphically higher layer, these remains would indicate, at the very least (given the thickness of the outcropping section) that the main fossiliferous level would be situated less than 10 m below unambiguously Vallesian levels.” Given average sedimentation rates for the basin of ca. 20 cm/kyr (see references in the manuscript), that would represent around 50 kyr below contrasted Vallesian levels, thereby constraining to a great extent the possible magnetostratigraphic correlations of the sampled magnetozones.**

Furthermore, your correlation of the original ‘layer 1’ from the 1965-1981 collections to your ‘layer D’ seems to be based solely on the personal communication of JV Santafé. That’s potentially not a problem, but I would be better to explicitly explain how s/he did it. Did s/he come to the field? Were there notes or old photos that were consulted? This would help to persuade readers that you really do have the same layer.
**Yes, Santafé came to the field as already indicated in our previous version (L193-195): “was located thanks to the collaboration of the late Josep V. Santafé, who had repeatedly excavated the site during the 1970s with Crusafont, and indicated the exact location while visiting the site during the 2015 season”. We were unable to find contextual photographs of the site that could help to locate it and the published notes about its location, as explained in the manuscript, were too vague. It must be stressed that one of the authors of the present manuscript also visited and briefly excavated the site in the late 1970s, but was not able to remember the location of the spot until Santafé came to the field. The latter had intensively worked at the site, and when he arrived he went straight to the spot and told us where to excavate. Once we removed the overlying soil and plants, a layer was uncovered that displays color and other sedimentological features that are in agreement not only with the remembrances of both Santafé and the coauthor of the paper, but also with sediment fragments preserved in the collections attached to some fossils from this site. Santafé confirmed that they stopped excavating the site because the bone accumulation from the main layer had been exhausted, but this does not mean that further fossils cannot be found, as this had been always the case for the whole section. Given that we already explained that Santafé came to the field in 2015, we do not think it is necessary to provide further explanations, but could do so if the editor and/or the reviewer consider it necessary.**

Your stratigraphic layers should be shown in Figure 5.
**As explained above, we have provided a new supplementary figure to provide more details about the stratigraphy, given that Figure 5 is focused on the paleomag results and the size of the profiles does not enable for additional details. Note that in the new figure**

**we have only named the layers that yielded fossil remains, as doing otherwise would represent an unnecessary complication.**

If you reorganize M&M to go through the paleomag methods first, then I would suggest the same organization for the Results section.
**Done. The subsections have been renumbered accordingly.**

This may be my preference, and you should check with the AE, but I think that some material currently in 'Discussion' could be moved to 'Results'. For example, some of the basic chronostragraphic interpretations of the rodents (starting on Line 357) could be moved.
**We disagree. In our opinion, the paragraph beginning at L357 of the previous manuscript better fits the Discussion, as it provides the required context to understand the main implications of the rodent assemblage from the site. Only the passage beginning at L369 ("In the case of CB, the most significant datum provided by the rodent assemblage…") could be moved by the Results, but it would not make much sense without the rest of the paragraph and it should be restated again in the Discussion. So unless the editor has a different view, we prefer not to modify the Discussion in this regard.**

Lines 414-417. If that's the case, then you should delete most of this paragraph. It's really not relevant to your paper to provide an explanation of taxonomy within *Hippotherium* if you aren't going to assign the humerus to a species. This is a good place to shorten up the rather lengthy discussion on this topic. I wonder if all of the following paragraph (lines 418-434) is necessary either.
**The reviewer alludes to our sentence "we refrain from attributing the CB scanty specimens to this species [*Hippotherium* (*primigenium*) *catalaunicum*], because they do not allow to ascertain its purportedly derived distinguishing features from *Hippotherium primigenium* s.s." and suggests to delete most of the paragraph. We disagree from the reviewer, in the sense that s/he considers the discussion about the taxonomy irrelevant because we provide no assignment to species, whereas we consider it relevant precisely to justify our inability to provide an assignment to species. Furthermore, this paragraph is required to explain our assignment for other remains of the genus from the Vallesian of the Vallès-Penedès Basin, which are assigned to *H. catalaunicum* instead of *H. primigenium*. Given the controversies about hipparionin taxonomy, we prefer to be clear-cut in this regard. Similarly, we also would like to keep the paragraph that follows the sentence alluded by the reviewer. Given that our conclusions indicate that CB is probably roughly coeval with the earliest occurrence of *Hippotherium* in the Vallès-Penedès Basin at Creu de Conill 20, the fact that the latter represent one of the few well-dated earliest occurrences of this taxon in Western Europe, and the great biostratigraphic importance of**

**the taxon for defining the Vallesian, we feel that contextualizing our finds from these viewpoints is warranted. We nevertheless remain open to suggestions from the editor if he considers that the manuscript needs to be shortened.**

Minor Comments:

The term 'classical' is heavily overused in the manuscript, and isn't a great translation into English. In many places the term 'original' could be substituted (as in 'original outcrop'). When it refers to the material excavated in the original phase of research from 1965-1981, you could explicitly explain that, or refer to it as "previously collected material" (e.g. line 44-45) or "museum collections" (line 64). Once you've explained that your 'level D/layer D' is the same as the 'classical fossiliferous level', then you can probably just call it Layer D.
**We agree, and therefore changed all occurrences of 'classical' using the various alternatives suggested by the reviewer or even deleting the word when it was not necessary. As explained above, Layer D was most of the time substituted by CB-D.**

Throughout – this may relate to how other previous publications have treated Spanish surnames, but the hyphen use for several names is inconsistent. For example, what I believe is a single person is sometimes referred to as just "Crusafont", sometimes as "Crusafont-Pairó", and sometimes as "Crusafont Pairó" (no hyphen). Other impacted names include Golpe (also Golpe-Posse and Golpe Posse) and Santafé (Santafé Llopis, Santafé i Llopis). To the extent possible, these should be standardized.
**The reviewer is right, except that the use of these surnames is consistent with that employed by these authors in the original publications. People have two surnames in Spain, and sometimes use only one of them, sometimes both, somethings unite them with a hyphen, and sometimes with an 'i' (in Catalonia). The original authors are to be blamed for not having consistently spelled their names, but we think it is preferable to be consistent with the published literature, and this is indeed the criterion that I (the first author) have used in all my publications for many years. Therefore, no changes were introduced in this regard.**

Does it really help to abbreviate the site name to 'CB' in the text? It's done inconsistently (particularly in figure captions), and doesn't really make the paper easier to read. I might just use the full site name throughout the manuscript (except of course on figures themselves – e.g. using 'CB1' to refer to the section). If you don't abbreviate Castell de Barbarà, then it's probably not necessary to abbreviate CCN20 or ACM either [note that ACM is not explained in the text].
**CB was spelled out in each figure caption because in principle figures should stand on their own grounds and it is better not to use undefined abbreviations (even if explained in**

**the text). With a few exceptions, the CB abbreviation was consistently used elsewhere in the text, like that of CCN, so that only ACM needed to be spelled out (this was an inadvertent mistake). However, following the reviewer's request we have mostly abandoned the use of site abbreviations in the revised manuscript. We have only specified once within parentheses the abbreviation for Creu de Conill 20 (for it is widely employed in the literature), and have also specified the abbreviations for the various Castell de Barberà localities that yielded fossil remains in 2014-2015 in the supplementary material. Therefore, we have not employed CB to refer to Castell de Barberà, but have used CB-D to refer to Layer D. Note that, as a result of this change, the Abstract would have been lengthened slightly above generally permitted extension of 300 words. However, this is not the case thanks to the edits provided for the abstract by reviewer 1.**

Lines 129-136. I'm struggling to understand the logic here. First, who are the 'latter authors'? If it's Crusafont-Pairó and Golpe-Posse (1974), then I don't understand how they could have 'only contemplated two possible explanations', because they are the ones who thought the fossil came from a higher level (so that would be three explanations). If, instead, it was Santafé Llopis 1978 who suggested the fossil came from a higher level, then that isn't the 'latter author' (nor is it 'most authors' as reported on line 381). In this scenario, it might be worth clarifying that Crusafont-Pairó and Golpe-Posse (1974) accepted that the *Hippotherium* fossil came from the main fossiliferous level before outlining their interpretations. Furthermore, their second interpretation (that the boundary was located 'along the upper portion' of the section, doesn't seem to logically follow. I think these lines could use some clarification.

**We have tried to clarify this passage, for example, by specifying that the "latter authors" are indeed Crusafont-Pairó and Golpe-Posse (1974). The reference by Santafé Llopis (1978) was only to back up the location of the main fossiliferous layer at about midheight of the ca. 20 m-thick stratigraphic section, but in the revised version we have omitted it, as this was also stated by the former authors. Note that Crusafont-Pairó and Golpe-Posse (1974) considered it likely that the *Hippotherium* fragment came from the upper layer, but they were not sure about it, which is the source of their two different interpretations. We nevertheless understand that the reviewer has problems understanding the logic of Crusafont-Pairó and Golpe-Posse (1974), because it is quite contorted and stems from Crusafont's a priori assumption that Castell de Barberà must undoubtedly predate the Vallesian (as explicitly stated in their paper). We reproduce below the relevant fragments from Crusafont-Pairó and Golpe-Posse (1974; our translation from the Spanish original), so the reviewer can judge by him/herself whether our summary of their interpretation is faithful to the original or not:**

**"...the finding of a somewhat rounded fragment (the only one among thousands of specimens) of *Hipparion*. [...] The bank of the Ripoll River, where the considered site**

**[Castell de Barberà] is located, has about 20 m of depth. The fossiliferous layer, undoubtedly Vindobonian, is located at about midheight. However, on the other hand, there is another layer closer to the top of the wall border, from where, probably, the aforementioned *Hipparion* fragment come from. [...] the upper layer, from which, on the other hand, no further *Hipparion* remains have been found, is still Vindobonian and represents the first appearance, very shy, of Christol's genus? Or, in contrast, the lower layer is the top of the Vindobonian and the upper one is already Vallesian? This is a very difficult problem that could not be solved except by means of better findings from the upper layer. It is not possible that the fragment comes from layers considered by us as Vallesian (Can Llobateres I, Can Llobateres II, Santiga, etc.), given the presence of a forested area in the upper portion of the riverbank, with dense vegetation that covers a relatively extensive area".**
**We have expanded our sentences in this regard to be more clear-cut, as we acknowledge that our original fragment was too succinct and could led to misinterpretations. The revised version reads as follows: "Crusafont-Pairó and Golpe-Posse (1974) considered that the main fossiliferous layer was undoubtedly pre-Vallesian and only contemplated two possible explanations for the presence of *Hippotherium* at the site: either *Hippotherium* arrived in the Vallès-Penedès Basin during the latest Aragonian (irrespective of whether the aforementioned fragment came from the main or the upper fossiliferous layers); or the Aragonian/Vallesian boundary was located above the main fossiliferous level along the upper portion of the Castell de Barberà section (assuming the *Hippotherium* fragment came from the upper layer)"**
**Note that we talk about *Hippotherium* and Aragonian instead of *Hipparion* and Vindobonian, as in the original publication, to avoid introducing unnecessary confusion.**

P. 6. Regarding the original *Hippotherium* material reported by Crusafont-Pairó and Golpe-Posse (1974), it would be worth clarifying what this specimen was. Was it one of the dental specimens mentioned later in the text?
**As already asserted later in our original manuscript (L286-287, subsection 3.2., "Presence of *Hippotherium*"; currently renumbered as subsection 3.3.), "It is uncertain on the basis of what specimen Crusafont-Pairó and Golpe-Posse (1974) originally reported the presence of *Hipparion* (currently, *Hippotherium*) at CB". We continued to explain that two dental specimens of this taxon (once already reported by Rotgers and Alba, 2011, the other never figured or described) are available from the collections of the site. Crusafont-Pairó and Golpe-Posse (1974) did not report a collection number, describe or figure the purported *Hippotherium* fossil from Castell de Barberà, and merely referred to it as "a fragment" without even specifying whereas it was dental or postcranial, but merely noting that it was "somewhat rounded". The lower molar figured by Rotgers and Alba (2011) is well preserved and therefore unlikely to correspond to the original report by**

**Crusafont-Pairó and Golpe-Posse (1974). In contrast, it might apply to the deciduous premolar germ newly mentioned in our manuscript, although it is impossible to be sure. This has been noted, albeit with doubts, in the revised manuscript (although not in the section alluded by the reviewer, but after the report of the two hipparionin teeth from the site): "Crusafont-Pairó and Golpe-Posse (1974) did not figure or describe the specimen attributed by them to *Hippotherium*, but merely referred to it as a somewhat rounded fragment—which might apply to the above-mentioned deciduous premolar, although it is not possible to be certain."**

P. 7. The reader requires some explanation of the age of Can Llobateres in order to understand the significance of their close stratigraphic distance.
**Done, we have specified that we referred to Can Llobateres 1 and provided an updated interpolated age for the locality with the corresponding reference.**

Lines 184-188. You make it sound as if there was some huge delay, but if the fieldwork was planned for 2014, and some fieldwork really happened in 2014, then this can probably be omitted. Also, it would also probably suffice to say that the modifications of the river bank were to build 'a road'.
**The reviewer alludes to our sentence: "This fieldwork initiative was hampered by the vagueness of published indications about the site's exact location (Crusafont-Pairó and Golpe, 1972; Golpe Posse, 1974), coupled with decades of vegetation growth and recent anthropic modifications of the river bank (to build a roadway in the framework of a riverine park)." Indeed there was a considerable delay, because the indicated reasons apparently precluded Miguel Garcés from sampling the site for his dissertation (1995) on the magnetostratigraphy of the Vallès Sector of the Vallès-Penedès Basin (see also Garcés et al., 1996, cited in the text). Nevertheless, in this sentence we did not want to imply a temporal delay, but merely refer to the difficulties to locate the site to begin with. In the revised version we have therefore rephrased the sentence as: "Finding the exact location of the site was hampered by the vagueness of published indications ...". Following the reviewer's suggestion, we have also omitted allusion to the riverine park, but have rephrase this portion of the sentence as "recent anthropic modifications (to enlarge the riverbank's trackway)", which in our opinion better describes the situation and is about as short as the alternative suggested by the reviewer "recent anthropic modifications of the river bank (to build a road)"**

Lines 290-291. The presence of a second specimen in the collections is not a valid reason to accept the provenance of IPS57437. They are independent specimens and must be treated as such. Again, the presence of either of these specimens, even if they are really from

Castell de Barbarà, isn't particularly helpful if they could have come from the 'higher layer' of the 1965-1981 collections.

**Rephrased not to give such impression. There is no reason to question the provenance of the specimens (as the reviewer seems to implicitly suggest), in the sense that the site was clearly recorded in the labels. We disagree that these specimens are not relevant, for the reasons already explained above. The two layers are quite close, implying a small difference in age and at the very least a correlation with the Vallesian for the uppermost portion of the section, which is of utmost significance for anchoring the paleomag results. This was already stressed in the Discussion section (L385-388: "Even if both teeth came from a stratigraphically higher layer, these remains would indicate, at the very least (given the thickness of the outcropping section), that the main fossiliferous layer would be situated less than 10 m below unambiguously Vallesian layers."). However, given the concerns raised by the reviewer, in the revised version we have also briefly stressed this fact in the alluded paragraph of the Results section.**

Line 366. Why would the latest Aragonian subzone be called this? Why would *Hippotherium* be in the name if your whole argument is that *Hippotherium* is not present in the Aragonian?

**The reviewer wonders why the latest Aragonian subzone is called "*Democricetodon crusafonti – Hippotherium* interval subzone" according to Casanovas-Vilar et al. (2016b). These authors first provided a formal diagnosis and description of each zone, and followed Murphy and Salvador (1999, International Stratigraphic Guide, An Abridged Version) in naming the zones after their diagnostic taxa, and distinguished between 'assemblage', 'concurrent' and 'interval' (sub)zones. The subzone alluded by the reviewer was defined by Casanovas-Vilar et al. (2016b, p. 205) as follows: "The base is defined by the FLO [first local occurrence] of *Democricetodon crusafonti*, the top is defined by the FLO of the equid *Hippotherium*". So the interval subzone alluded by the reviewer includes *Hippotherium* merely because it was defined following the relevant stratigraphic guidelines, which indicate that "the names given to interval zones may be derived from the names of the boundary horizons, the name of the basal boundary preceding that of the upper boundary; e.g. *Globigerina sicanus-Orbiculina suturalis* Interval Zone" (Murphy and Salvador, 1999, p. 263). This has been briefly explained in the revised version by means of a footnote to prevent misunderstandings: "Interval zones are defined by two specified biohorizons (in these cases, corresponding to the lowest occurrences of the specified taxa), and termed with the name of taxon defining the basal boundary preceding that of the taxon defining the top boundary (Murphy and Salvador, 1999)."**

Lines 530-543 – discussion of paleoenvironments. I know that Sukselainen et al use the term 'humid' in their paper, but their work is really a better proxy for 'precipitation', which I think

would be the more appropriate term to use here. For many English readers, the term 'humid' is going to invoke 'humidity' and specific types of forest, but what you're really talking about here is a forest (as opposed to a non-forest), and not a necessarily a very 'humid' one. The presence of beavers doesn't necessarily indicate high humidity, just the presence of permanent water bodies. Your other rodents certainly do indicate 'forests' as opposed to non-forested conditions, and I think this would be the more important point to emphasize. Also, line 543 would make more sense if you explain what the predominant paleoenvironments are for most late Aragonian localities. Presumably, they are drier… but are they dry forests or something else? Finally, there's no reason that I can see that these have to be 'exceptionally' humid conditions (line 587). Consider removing 'exceptionally'.
**We do not completely agree with the reviewer's interpretation. Sukselainen et al. (2015) relied on hypsodonty as "a proxy for vegetation structure on an axis from closed to open […], which in turn has been used as a proxy for past humidity and precipitation" (p. 25; see also their p. 36: "Previous studies have shown that the mean ordinated hypsodonty of large herbivorous mammals can be used as a proxy for past humidity and precipitation"). Therefore, we acknowledge that the reviewer is right when s/he says that Sukselainen et al.'s results are more directly indicative of vegetation structure, but specifically disagree with the reviewer's contention that their results are more a proxy for precipitation than for humidity itself. We do not think these two aspects can be easily disentangled based on hypsodonty, since the latter is more directly related to vegetation structure, and only through the latter linked to both humidity and precipitation. We acknowledge that, following Sukselainen et al. (2015), we were using the term 'humid' too losely to refer to both humidity s.s. and precipitation, so this has been corrected in the revised version by putting the term 'humid' (sensu Sukselainen et al.) between quotation marks and adding the following clarifying statement: "This study relied on the hypsodonty of larger herbivorous mammals as a proxy for vegetation structure, which in turn has been used as a proxy for past humidity and precipitation (Sukselainen et al., 2015, and references therein), so that their conclusions are more adequately interpreted as indicating more closely forested conditions for primate-bearing localities (particularly those in which the two groups co-occur) as a result of higher humidity (moisture), precipitation (rainfall), or both.". Further clarification in this regard has been also added regarding the interpretation of the results for Castell de Barberà by Casanovas-Vilar et al. (2008) in the following sentence.**
**We further dissent to some extent with the reviewer's assertion that beavers do not indicate high humidity in the case of Castell de Barberà. As a general assertion, the reviewer is right, and in the previous version we already explictly recognized that beaver abundance at this particular locality indicated "the presence of permanent water bodies" (L536), as noted by the reviewer. Nevertheless, in the Vallesian of the Vallès-Penedès Basin, sites located near water bodies, such as Can Llobateres, have been interpreted as**

**most representative of the habitats that enabled the presence hominoid primates (see Marmi et al., 2012, added to the revised version, as well as Alba et al., 2018c). This has been further clarified in the revised version by adding the following sentences: "These taxa indicate the presence of permanent water bodies nearby, although not necessarily of humid and densely forested habitats. Nevertheless, in the framework of Vallès-Penedès regional setting it is consistent with the fact that Vallesian hominoids from this basin have been linked to forested humid habitats providing a year-round fruit supply (Marmi et al., 2012; Alba et al., 2018c)—such as that from Can Llobateres 1, which on the basis of plant remains has been reconstructed as a very humid marshy area with nearby dense wetland forests including some (sub)tropical elements (Marmi et al., 2012). The record of the anuran *Latonia* is also indicative of locally humid and warm conditions (Villa et al., 2017), and besides the presence of primates and beavers, a closed forested environment at Castell de Barberà is further supported by the presence of certain forest-dwelling taxa [...] Finally, certain cricetids (*Eumyarion*, *Anomalomys*) may have also preferred densely forested habitats because they tend to be more abundant in fossil faunas rich in glirids and flying squirrels (Casanovas-Vilar and Agustí, 2007)".**

**The sentence from L542-544 alluded by the reviewer ("The earliest Vallesian age supported here for CB indicates that this site must no longer be considered a paleoenvironmental oddity among late Aragonian localities, but rather the best known earliest Vallesian locality from the Vallès-Penedès Basin") has been completely rewritten as "The apparently more humid and densely forested paleoenvironmental conditions of Castell de Barberà as compared to late Aragonian localities from the same basin could be explained to some extent by differences in age. However, even if the earliest Vallesian is not well represented in the Vallès-Penedès, Castell de Barberà should not be taken as representative of the dominant paleoenvironments in the basin as a whole during this time span—as suggested by differences in faunal composition from the roughly coeval Creu de Conill 20 site...". Furthermore, additional considerations have been added at the end of this paragraph regarding the paloenvironmental characterization of Creu de Conill 20 as compared to Castell de Barberà based on the rodent fauna: "The rodent fauna of Creu Conill 20 is overwhelmingly dominated by the cricetid *Megacricetodon ibericus*, which is very rare at Castell de Barberà and is considered to have been a generalist probably preferring more arid woodlands (Daams and Freudenthal, 1988; Casanovas-Vilar et al., 2006, 2008, 2010, Casanovas-Vilar and Agustí, 2007). At Castell de Barberà, *Eumyarion leemanni* is the most abundant cricetid, which is consistent with the occurrence of locally humid and forested environments."**

**Finally, "exceptionally" was used in the sentence from L587 (and also L530) to mean "to a greater degree than normal; unusually" (definition from the New Oxford American Dictionary). Given the reviewer's concern in this regard, we changed it into "particularly" (meaning "to a higher degree than is usual or average"), added "and/or densely forested"**

**after "humid", and also added "as compared to most other sites from the same basin" at the end to be more clear-cut.**

Line 576. You said on the previous page that no primates had been found at 'CCN20' and from your description there, it didn't sound too promising. So why now say that this area is 'most promising'? Please address this inconsistency.
**We agree with the reviewer that our previous assertions regarding CCN20 were a bit contradictory. The site is promising with regard to the age, less so regarding the paleoenvironment. The case is that Miocene primates are very rare in the Vallès-Penedès Basin, and the currently available sample (amassed during the 2016-2017 campaigns) is insufficient to conclusively rule out the presence of primates at the site. This is what we wanted to highlight, although we were not clear-cut enough. This has been fixed in the revised version by slightly rephrasing to some extent the sentence alluded by the reviewer as well as by expanding a bit the explanations provided in this paragraph. The revised version reads as follows: "Two different areas from the Vallès-Penedès Basin have the potential to yield additional primate remains roughly contemporaneous with those of Castell de Barberà [...]. The currently available sample of ca. 2000 macrovertebrate remains from Creu de Conill 20 is insufficient to dismiss the ulterior find of primates after additional sampling efforts at this locality (given the rarity of these taxa among Vallès-Penedès fossil assemblages), although the paleoenvironmental hints provided by the recovered fauna are not particularly promising in this regard (see above). This contrasts with the situation in the fossiliferous area of els Hostalets de Pierola, where the presence of an indeterminate dryopithecine is documented close to the Aragonian/Vallesian boundary by...".**

Figure 2 caption. I don't know what you mean by 'the bottom of sections samples'.
**Sorry, this was a typo ("samples" instead of "sampled"). It has been fixed in the revised version, which now reads as "bottom of sections sampled for magnetostratigraphy".**

Figure 3 caption could benefit from using A and B to refer to the two images? Note also that the legend in this figure uses ICS terminology, which should be addressed.
**This is the figure with the schematic geological map of the basin, which further includes an inset to show the location of the basin within the Iberian Peninsula as well as the legend for the depicted deposits. As we do not refer separately to the main map and to the inset in the main text, we think that adding lettering is unnecessary in this particular figure. As for the use of ICS terminology, we already explained our reasons above and added to the revised text the equivalence between Aragonian and Vallesian land mammal ages with official marine stages and the corresponding ages.**

Figure 5 caption. The terms CB s.l and CB s.s are never really explained. Consider omitting, as pointed out above.

**These terms have been omitted from this and other figures, but as stated above their meaning has been explained with additional details in the SOM.**

Figure 6 caption. As far as I can determine, the 'Aragonian' is not an ELMA term in any standard continental treatment (it's not used throughout Europe). Consider revising? Does MN need its abbreviation explained?

**This relates to the comments provided by reviewer 1 about the Aragonian, and as stated above additional explanations have been provided in this regard in the revised version. As for the caption of this particular figure, note that it is specified that European land mammal ages are after Casanovas-Vilar et al. (2016b). This paper is entitled "An updated biostratigraphy for the late Aragonian and Vallesian of the Vallès-Penedès Basin (Catalonia)" and throughout the text and figures of that paper the three ELMA employed are Aragonian, Vallesian and Turolian (e.g., Casanovas-Vilar et al., 2016b: Fig. 6). So it would be inconsistent not to use the term Aragonian. Authors dealing with the Iberian record consistently use 'Aragonian' and do not even mention the 'Astaracian' (e.g., Garcés et al., 1996; Agustí et al.; Casanovas-Vilar et al., 2016b), which is not surprising given that the former is a formally defined continental stage (even if of regional applicability), whereas the latter is still a loosely defined biochronological unit. As explained above in our response to reviewer 1, this issue has been discussed in greater detail in the revised version, and the fact that the Aragonian is only applicable to Spain does not make it less European than others that are not applied to Spain. The Spanish record has played a major role in the definition of widely accepted (and formally defined) European land mammal ages (Vallesian and Turolian), and the failure to recognize the Aragonian in nearby countries such as France is more attributable to the lack of tradition and will of French paleontologists than to the inability to adequately correlate the main bioevents. Nevertheless, one must acknowledge that the detailed biostratigraphical divisions in the Aragonian type area (which include subzones lasting just a few hundred kyr) are most likely local to regional, as it occurs with the detailed Vallesian zones in the type area (see Casanovas-vilar et al., 2016b for a discussion). Overall, we consider that the reviewer concerns are adequately addressed with the newly added introductory subsection on the Aragonian and the Vallesian. As for the meaning of MN ("Mammal Neogene zones"), in the revised version it has been specified when first used in the main text (subsection 1.2 of the Introduction).**

<u>Editorial Suggestions:</u>

The English is very good, and my only real concern is the use (and overuse!) of the term 'classical', as outlined above. I have made a few suggestions on wording and caught some typos:
**We thank the reviewer for the detailed corrections. 'Classical' has been corrected as explained above.**

Line 15: Delete 'a' to modify to 'precluded more accurate dating'
**Done.**

Line 52 – clarify 'whose provenance' – does this refer to the hominoid or pliopithecoid remains? If it's the pliopithecoids, then you could simplify the sentence to read "remains, which are attributed to the main….".
**It referred to the pliopithecoids, corrected as suggested by the reviewer.**

Line 116 – delete the comma after 'currently.'
**This no longer applies, following the simplification of the sentence to avoid mentioning 'Vindobonian', as explained above.**

Line 146 – "real scarce" is too informal. Substitute something like "even if *Hippotherium* was scare or even absent from the site."
**Done.**

Line 164-165 "remained open TO (refs), or even supported (refs), an alternate…"
**Done.**

Line 190. Do you need to say 'Miocene' here? Is there any other section represented? If so, that should probably get explained somewhere.
**Deleted. There are Quaternary sediments on top of the sections, but this needs not be mentioned in the manuscript.**

Also Line 190. 'situated less than 300 m FROM the….'?
**Done.**

Line 196 – 'although our work (no s) confirmed that bone accumulation of THE main fossiliferous level of CB is exhausted, they enabled the recovery of additional fossil remains…'. It would be important to say WHERE these additional remains come from.
**The two typos noted by the reviewer have been fixed and the sentence has been modified as further explained above. More details about the provenenace of new fossil remains has been provided in the SOM (see also above).**

Line 235 – say ‘east’ instead of ‘E’.
**Done.**

Line 236 – what is ‘only minimally higher than 95m’? Perhaps give the actual measurement or say ‘approximately 95 m ‘.
**We meant that both were at 95 m with differences in the first decimal, changed into “~95 m”.**

Line 251. I’m not sure that ‘Natural Remanent Magnetization’ needs to be capitalized. Also, the abbreviation (NRM) should appear right after the term.
**Agree, both capitalization and abbreviation fixed.**

Line 252. Should this be ‘until complete demagnetization’? I’m not sure.
**Reviewer 1 also suggested an alternate phrasing, but our expert in paleomagnetisms insists on the original expression. A search in Scholar Google reveals that “up to complete demagnetization” is a common expression in papers devoted to paleomagnetism published by other authors (e.g., Di Stefano et al., 2015 Newsletters on Stratigraphy 48(2), 135-152; Fernández-Lozano et al., 2016 Tectonophysics 681, 195-208; Veselovskiy et al., 2017 Izvestiya, Physics of the Solid Earth, 53(6), 898-907).**

Line 295 – the second “Vallesian” in this line appears to be out of place?
**Deleted.**

Line 300 – for simplicity, you can probably delete ‘in several fragments’
**We substituted “broken in several fragments” by “fragmentary”.**

Line 308 – substitute ‘attribution’ for ‘assignment’
**Done as per reviewer’s request, although we do not understand the rationale, because both terms are synonymous within a taxonomic context, and the reviewer did not request us to change other instances in which “assignments” was used with the same meaning throughout the manuscript.**

Line 345 – modify for simplicity to ‘uncertainties remain, because it is impossible to completely dismiss the presence of one or more…”
**Changed as suggested.**

Line 361 – substitute ‘largely’ for ‘being mostly’.
**Done.**

Line 380 - change ‘find’ to ‘presence’
**Done.**

Line 382 – delete comma after ‘significance’.
**Done.**

Line 407 – delete ‘the’ to make it ‘material from els Hostalets de Pierola’.
**Done.**

Line 521 – change ‘such’ to ‘this’
**Done.**

Line 525 – change ‘of’ to ‘from’
**Done.**

Line 528 – delete ‘even’.
**Done.**

Line 558 – change ‘between’ to ‘of’
**Done.**

Line 562 – simplify to “the results of this paper provide an accurate date for this taxon”
**Done.**

Line 571 – what is ACM? I don’t think this abbreviation was defined.
**The reviewer is right, we inadvertently failed to spell it out. It has been substituted by Abocador de Can Mata in the revised version.**

Line 580 – I would just write out ‘female lower canine’.
**Done, even though dental abbreviations are considered standard and need not be spelled out in this journal.**

Line 582 – is Can Mata 1 part of Hostalets de Pierola? (e.g. a subsite or a specific level?)
**Els Hostalets de Pierola is a fossiliferous area that covers a time span of about 3 Myr and includes about two dozens of ‘classical’ sites (mostly, but not exclusively, located within the hominimous municipality), plus >200 late Aragonian fossil localities from the macrosite of Abocador de Can Mata (ca. 12.5-11.5 Ma) and several Vallesian additional ones from the nearby macrosite of Ecoparc de Can Mata. Can Mata 1 is one of the best**

**known ‘classical’ sites, and corresponds to a locality in a strict sense (i.e., equivalent to a single geological layer). This is explained in several of the cited references in this sentence (Alba, 2012; Alba et al., 2013), so we think it needs not be explained in greater detail in the manuscript. However, we have slightly modified the passage to be more clear-cut: addition of “fossiliferous area of” before “els Hostalets de Pierola” and of “fossil locality” before “of Can Mata 1”.**

Line 591 – change ‘samplings’ to ‘sampling’
**Done.**

Line 596 – change ‘dating’ to ‘date’
**Done.**

Lines 606-609. Consider “…provided in this paper is important to contextualize the faunal and paleoenvironmental changes that enabled the coexistence of pliopithecoids and hominoids at some sites in the Vallès-Penedès Basin during the late Miocene.”
**Thanks, rephrased as suggested by the reviewer.**

Figure 4 caption. Do you mean ‘*H. catalaunicum*’?
**Yes, spelled out as *Hippotherium catalaunicum* in the revised version.**

**Other changes:**

**We corrected a few additional typos and made some minor edits throughout the manuscript (see the revised version of the main text with tracked changes).**

**We added an affiliation that was inadvertently missing from the last author.**

**The reference corresponding to the citation Ogg (2012) was missing from our previous version and has been added. This reference was in a couple of occasions incorrectly cited as Ogg et al. (2012), and this has also been fixed in the revised version. Multiple additional references have been added due to the additions required to address the reviewer concerns.**

**In the Acknowledgments of the revised version (provided in the title page, which is not sent to reviewers), we have thanked the comments and suggestions by the editor and the reviewers (those of reviewer 1 by name, since he disclosed his identity).**

# Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian~~: End of the controversy~~

**Keywords:** Hominoidea; Pliopithecoidea; *Hippotherium*; Late Miocene; Magnetostratigraphy; Paleomagnetism.

**Abstract**

Castell de Barberà~~ (CB)~~, located in the Vallès-Penedès Basin (NE Iberian Peninsula), is one of the few European sites where pliopithecoids (*Barberapithecus*) and hominoids (cf. *Dryopithecus*) co-occur. The dating of this Miocene site has proven ~~very~~ controversial. A latest Aragonian (MN7+8, ca. 11.88–11.18 Ma) age was long accepted by most authors, ~~in~~ despite ~~of~~ subsequent reports of hipparionin remains that signaled a Vallesian age. On the latter basis, Castell de Barberà~~B~~ was recently correlated to the early Vallesian (MN9, ca. 11.18–10.3 Ma) on tentative grounds~~ (ca. 11.18–10.3 Ma)~~. Uncertainties about the provenance of the *Hippotherium* material and the lack of magnetostratigraphic data precluded~~ a~~ more accurate dating. After decades of inactivity, fieldwork was resumed in 2014–2015 at ~~CB~~Castell de Barberà, including the ~~classical~~ original ~~horizon (‘l~~layer ~~D’~~(CB-D) that in the past delivered most of the fossils. Here we report ~~the results of~~ magne~~s~~t~~r~~ostratigraphic results ~~analyses performed in~~for the ~~classical~~ original outcrop and ~~in~~ another nearby section. Our results indicate that CB-~~layer~~ D is located in a normal polarity magnetozone at about midheight of ~~the~~ a short (~20 m-thick) ~~classical~~ stratigraphic section. The~~y also imply that the~~ composite magnetostratigraphic section (~50 m) has as many as four to six ~~different~~ magnetozones. These multiple reversals, coupled with the in situ recovery of a *Hippotherium* humerus from ~~layer~~ CB-D in

2015, ~~rule out~~make it very unlikely the correlation of any of the sampled normal polarity magnetozones with the long normal polarity subchron C5n.2n (11.056–9.984 Ma), which is characteristic of the early Vallesian. Our results support instead a correlation of CB-~~layer~~ D with C5r.1n (11.188–11.146 Ma), where the Aragonian/Vallesian boundary is situated, and therefore ~~unambiguously~~ indicate an earliest Vallesian age of ~11.2 Ma for ~~CB~~Castell de Barberà. ~~This~~ Our results ~~conclusively~~ settle~~s~~ the longstanding debate about the Aragonian vs. Vallesian age of this site, ~~being~~ which appears roughly coeval with the ~~site of~~ Creu de Conill 20 locality (11.18 Ma), ~~which represents the first appearance datum of~~where hipparionins are first recorded in the Vallès-Penedès Basin.

## 1. Introduction

### *1.1. ~~The~~ ~~P~~primates from Castell de Barberà*

The Miocene primate-bearing site of Castell de Barberà ~~(CB)~~ is situated along the left bank of the Ripoll River, near the old farmhouse of Ca n'Altimira, in the municipality of Barberà del Vallès (Catalonia, Spain). The site was named after a former medieval castle (11th century) that was subsequently reconstructed as a country house. According to museum labels, the site was mostly excavated from 1965 to 1981 by personnel from the former Instituto Provincial de Paleontología in Sabadell, currently the Institut Català de Paleontologia Miquel Crusafont (ICP), although the site was already mentioned in the catalog published by Crusafont and Truyols (1954). Crusafont Pairó and Hürzeler (1969) first reported the find of primate remains, and Crusafont-Pairó and Golpe (1972) later provided a summary account of the site, noting that methodical excavations had been carried out there. Although publications based on the ~~classical~~ previously collected material from ~~CB~~ Castell de Barberà have continued until recently, the site was not excavated for many years, until it was reopened in 2014 and 2015 under the direction of author#6 and author#7.

Among the Miocene primate-bearing sites of Europe, CB Castell de Barberà is particularly renowned forby being one of the few in which pliopithecoids and hominoids co-occur (Moyà-Solà et al., 1990; Andrews et al., 1996; Alba, 2012; Sukselainen et al., 2015). In fact, it is unknown whether the hominoid remains come from the very same level layer as the pliopithecoid remains, whose provenance iswhich are attributed to the main fossiliferous layer that also yielded most of the fossils from the site (Alba and Moyà-Solà, 2012). However, the shortness of the stratigraphic section, coupled with the lack of any obvious hiatuses, implies that all of the fossils from the site are roughly coeval.

Hominoids were first reported from CB Castell de Barberà by Crusafont Pairó and Hürzeler (1969), based on a purportedly female right upper canine (IPS1823 [IPS26 in old terminology]; Fig. 1L) that was subequently attributed (either implicitly or explicitly) to *Hispanopithecus laietanus* (sometimes included in *Dryopithecus*; Crusafont-Pairó and Casanovas Cladellas, 1973; Golpe-Posse, 1974; Golpe Posse, 1982, 1993; Harrison, 1991). Even though other authors later assigned this specimen to a male pliopithecoid (Begun, 2002a; Alba et al., 2011; Almécija et al., 2011, 2012; Alba and Moyà-Solà, 2012), hominoids are also recorded at CB Castell de Barberà by several postcranial remains. These were found among the classical museum collections in the late 1980s, asbeing preliminarily reported preliminarily by Moyà-Solà et al. (1990), and subsequently described in detail. The hominoid specimens consist of: a distal humeral diaphysis (IPS4334; Fig. 1O; Alba et al., 2011; Almécija et al., 2011), a proximal pollical phalanx (IPS4333; Fig. 1N; Moyà-Solà et al., 2005; Almécija et al., 2012), and a distal pollical phalanx (IPS4335; Fig. 1M; Almécija et al., 2012). Based on the large body mass inferred from the humeral shaft fragment, the hominoid from Castell de Barberà~~CB~~ was tentatively referred to cf. *Dryopithecus fontani* (Alba et al., 2011; Almécija et al., 2011; Alba, 2012; Marigó et al., 2014), although such a tentative attribution cannot be further substantiated due to the lack of craniodental specimens (Almécija et al., 2012).

The pliopithecoid from Castell de Barberà~~CB~~, in turn, was first reported by Crusafont-Pairó (1975), based on several upper and lower teeth of a single individual (Fig. 1A–K) that was initially referred to *Pliopithecus* sp. Afterward, the lower dentition was described by Crusafont-Pairó and Golpe-Posse (1981a, 1982a), who similarly assigned the material to *Pliopithecus* sp., albeit noting similarities with *Pliopithecus lockeri* (currently in *Plesiopliopithecus*, i.e., a crouzeliid; Begun, 2002a; Alba and Berning, 2013). Some later authors advocated ~~for the~~ crouzeliid affinities for~~of~~ the Castell de Barberà~~CB~~ pliopithecoid (Ginsburg, 1986), but most ~~of them~~ considered it to be a pliopithecid (Andrews et al., 1996; Begun, 2002a; Harrison et al., 2002). Some authors even attributed the material (although usually ~~in a~~ tentatively ~~fashion~~) to *Pliopithecus antiquus* (Moyà-Solà et al., 1990; Andrews et al., 1996; Harrison et al., 2002), whereas others considered it to represent a new (unnamed) species (Ginsburg, 1986; Begun, 2002a; Alba et al., 2010). Finally, a new genus and species, *Barberapithecus huerzeleri*, was ~~erected~~ described by Alba and Moyà-Solà (2012) to accommodate the currently available dental remains, which belong to three different individuals: the holotype (IPS1724; Fig. 1A–K), including 15 upper and lower teeth from a single individual (see also Urciuoli et al., 2018); the paratype (IPS34548), consisting of a $P_3$ from another individual; and IPS1823, the aforementioned male upper canine (Fig. 1L), which was included in the hypodigm but not designated as a paratype. Finally, Moyà-Solà et al. (2013) preliminarily reported a proximal fragment of right radius (IPS66267) assigned to *Barberapithecus*, found by Lars van den Hoek Ostende while revising the collections, although this specimen has yet to be described in detail.

During the Miocene, hominoids and pliopithecoids did not co-occur at many sites, which constitutes~~ing~~ an apparent, although poorly-understood, pattern that has received ~~some~~ attention in recent publications (Sukselainen et al., 2015; Alba et al., 2017, and references therein). Both groups are represented in late Aragonian and Vallesian sites of the Vallès-Penedès Basin (see subsection 1.2. below for further explanation on these terms), although they seldom come from the same locality (exact stratigraphic horizon), even when their ranges are known to overlap as in Abocador de Can Mata (Alba et al., 2017). This fact might be due to a sampling artifact related to the rarity of these primates (Andrews et al., 1996), or it might be ~~alternatively~~ related to different ecological preferences between these groups (e.g., Sukselainen et al., 2015). As one of the few sites recording both groups and amenable to paleoecological analyses based on the accompanying fauna, Castell de Barberà~~CB~~ has the potential to shed ~~some~~ light on~~to~~ the particular conditions that enabled the infrequent coexistence of hominoids and pliopithecoids throughout the European Miocene.

### *1.2. ~~The controversial age of Castell de Barberà~~Vallesian and Aragonian European land mammal ages*

The contribution of Castell de Barberà~~CB~~ to a broader understanding of~~n~~ primate evolution during the European Miocene in general, and the succession of primate taxa at the Vallès-Penedès Basin in particular, has been ~~until now~~ hampered by a longstanding controversy about the age of this site—whether it correlates to the Aragonian or with the Vallesian European land mammal ages (ELMAs).

Some clarification is required with regard to the concept of ELMAs (for a historical review, see Lindsay and Tedford, 1990 and Van Dam, 2003), with particular emphasis on the use of 'Aragonian' instead of Orleanian + Astaracian, despite the latter are more widely used outside Spain. The use of ELMAs as geochronological units has been criticized (e.g., Steininger, 1999) on the grounds that they are regional and that, with few exceptions, they do not correspond to properly defined chronostratigraphic units (stages). 'Mammal ages' are generally conceptualized as "biochronologic units" (e.g., Woodburne, 2004a: xiv; see also Hilgen et al., 2012) of regional applicability due to divergent paleobiogeographic histories among regions (Lindsay and Tedford, 1990). However, an initial definition of land mammal ages as biochronologic units (i.e., biozones) is not mutually exclusive with their subsequent formal definition (based on bio- and magnetostratigraphic data) as chronostratigraphic units (i.e., stages based on bodies of rock formed during a given time interval; e.g., Garcés, 1995; Woodburne, 2004), which automatically implies the definition of their corresponding geochronologic units (ages).

The definition of regional chronostratigraphic units is not at odds with the International Stratigraphic Guide, because "It is better to refer strata to local or regional units with accuracy and precision rather than to strain beyond the current limits of time correlation in assigning these strata to units of a global scale" (Murphy and Salvador, 1999: 267). Even if not directly correlated with marine stages, regional continental units can be dated based on radiometric and/or paleomagnetic methods (e.g., Krijgsman et al., 1994; Garcés et al., 1996). Steininger (1999) conversely advocated abandoning a chronostratigraphic/geochronologic concept of ELMAs altogether and proposed to replace them by entirely biostratigraphic units ('European land mammal mega-zones') based on MN (Mammal Neogene) biozones (Mein, 1975). This proposal is not exempt of problems given that MN zones were defined as informal biochronologic units (Mein, 1975) and that their utility at a continental-wide scale is restricted due to the significant diachrony of most mammal biochronologic events (van der Meulen et al., 2011, 2012). This has led some authors to contend that a formal European biozonation is not possible (van der Meulen et al., 2012), which would imply that the regional nature of formally defined ELMAs such as the Aragonian (see review in van der Meulen et al., 2012) would rather be an advantage with regard to providing accurate correlations.

The lack of formal (biostratigraphic and chronostratigraphic) definition of widely used biochronological units such as Orleanian and Astaracian is a problem that does not apply to the roughly time-equivalent Aragonian, since like the younger Vallesian (which enjoys a wider geographic applicability) it has been formally defined on the basis of a specific stratotype. Crusafont Pairó (1950, 1951, 1953, 1995; see also Crusafont Pairó and Truyols Santonja, 1954, 1955) first used the term Vallesian in a largely biochronological sense to designate the Vallès-Penedès deposits with *Hipparion* (currently *Hippotherium*) that, based on the fauna, appeared intermediate in age between the sites of La Grive in France (i.e., the Aragonian) and Pikermi in Greece (i.e., the Turolian). The Vallesian was finally more formally defined in reference to Vallès-Penedès mammal successions by Crusafont Pairó and Truyols Santonja (1960) based on the entry of *Hippotherium* as its main defining criterion. The Vallesian was rapidly accepted throughout Eurasia as a simple solution for the complex stratigraphic terminology in use, although it was not until decades later that it was formally defined as a 'mammal stage' based on a specific stratotype from the type area (the Vallès-Penedès Basin) within an accurate bio- and magnetostratigraphic framework (Garcés, 1995; Garcés et al., 1996; Agustí et al., 1997). Following the proposal of MN zones by Mein (1975), MN9 and MN10 had already been equated with the early and late Vallesian, respectively, in turn subdivided into multiple local biozones based on rodents (Agustí, 1981, 1982; Agustí and Moyà-Solà, 1991; Agustí et al., 1997; Casanovas-Vilar et al., 2011a, 2016b).

The Aragonian was in turn originally conceptualized (Falhbusch, 1976) as a chronostratigraphic unit defined by the presence of the equid *Anchitherium* and the lack of the more derived equid *Hipparion* (currently *Hippotherium*), and subdivided into two subunits, the Orleanian and the Astaracian. Soon thereafter, the Aragonian was defined by Daams et al. (1977) as a new stage for continental middle Miocene deposits preceding the Vallesian, with its stratotype located within the Calatayud-Montalbán Basin in Spain (see also Daams et al., 1999). However, Daams et al. (1977) refrained from dividing the Aragonian into Orleanian and Astaracian because the latter had yet to be formally defined, ultimately leading to a tripartite subdivision (Daams and Freudenthal, 1981; Daams and Freudenthal, 1990). Moreover, the original criterion used to define the base of the Aragonian (the dispersal of *Anchitherium*) was soon questioned (Daams and Freudenthal, 1981) and eventually abandoned following the definition of the Ramblian stage (Daams et al., 1987; see also Daams and Freudenthal, 1990). Further stratigraphic refinements of the Aragonian were later provided by Daams et al. (1987, 1999) and van der Meulen et al. (2012), who further distinguished multiple Aragonian local biozones based on rodents. Based on these works, currently the Aragonian may be considered a regional mammal-based chronostratigraphic unit (stage), whose scope is limited to the continental record from Spain (see recent reviews in van der Meulen et al., 2012 and García-Paredes et al., 2016). Given the scope of this paper and the detailed local zonation of the Aragonian available for the Vallès-Penedès Basin (Casanovas-Vilar et al., 2016b), we refrain from using the alternative and more loosely-defined term ‘Astaracian’.

Based on high-resolution magnetostratigraphic correlation to the geomagnetic polarity time scale (GPTS), according to Van der Meulen et al. (2012) the early Aragonian (ca. 17.2–15.9 Ma) corresponds to the late Burdigalian (early Miocene, MN4), while the middle Aragonian (ca. 15.9–13.8 Ma) comprises most of the Langhian (early to middle Miocene, MN5), and the late Aragonian (ca. 13.8–11.2 Ma, roughly equivalent to the ‘Astaracian’) covers the latest Langhian, the Serravallian, and the earliest Tortonian (middle to late Miocene, MN6 to MN7+8). The Vallesian, in turn, entirely corresponds to the Tortonian (late Miocene), being subdivided into early Vallesian (11.2–10.0 Ma, MN9) and late Vallesian (10.0–8.9 Ma, MN10; e.g., Hilgen et al., 2012; Casanovas-Vilar et al., 2016b).

### *1.3. The controversial age of Castell de Barberà*

Originally, Crusafont and Truyols (1954), Crusafont-Pairó and Hürzeler (1969) and Crusafont-Pairó and Golpe (1972) advocated for a ~~‘Vindobonian’ (currently, late Aragonian) instead of~~pre-Vallesian age for Castell de Barberà~~CB,~~ because no hipparionin remains were originally found. Crusafont-Pairó and Golpe (1972), Crusafont-Pairó (1972), and Golpe-Posse (1974) remarked that the fauna appeared somewhat intermediate between those of the late Aragonian (MN7+8) and those of the early Vallesian (MN9) localities of the Vallès-Penedès Basin (e.g., Trinxera del Ferrocarril in Sant Quirze vs. Can Llobateres, respectively). However, given the lack of hipparionins~~*Hipparion* (currently, *Hippotherium*)~~ and the presence of giraffids, the above-mentioned authors correlated the site with the latest Aragonian. For many years, such a correlation was further supported by Crusafont and coworkers

(Crusafont Pairó and Golpe Posse, 1972a; Golpe-Posse, 1972, 1974, 1975, 1977, 1978; Crusafont-Pairó and Golpe Posse, 1972b, 1974, 1981a,b, 1982a,b; Petter, 1976; Santafé Llopis, 1978; Santafé i Llopis, 1978a,b), even in the face of a surface-collected fragmentary fossil of *Hippotherium* already reported by Crusafont-Pairó and Golpe-Posse (1974). ~~The latter authors~~According to Crusafont-Pairó and Golpe-Posse (1974), the *Hippotherium* ~~argued that this~~ specimen was somewhat rounded and probably eroded from the upper-most fossiliferous ~~level~~ layer of the Castell de Barberà~~CB~~ section, whereas most of the fossil assemblage (lacking *Hippotherium*) came from the main fossiliferous ~~level~~layer~~,~~ (situated at about the midheight of the ~20 m-thick outcrop~~ping~~ section ~~(Santafé Llopis, 1978~~). Crusafont-Pairó and Golpe-Posse (1974) considered that the main fossiliferous layer was undoubtedly pre-Vallesian and only contemplated two possible explanations for the presence of~~: either~~ *Hippotherium* at the site: either *Hippotherium* arrived in the Vallès-Penedès Basin during the latest Aragonian (irrespective of whether the aforementioned fragment came from the main or the upper fossiliferous layers); or the Aragonian/Vallesian boundary was located above the main fossiliferous level along the upper portion of the Castell de Barberà ~~local~~ section (assuming the *Hippotherium* fragment came from the upper layer).

Needless to say, the first possibility discussed by Crusafont-Pairó and Golpe-Posse (1974)—namely, a pre-Vallesian appearance of *Hippotherium*—is ~~just~~ an ad hoc explanation that does not hold upon~~a~~ closer scrutiny~~,~~ because it is at odds with the original ~~very same~~ definition of the Vallesian proposed by Crusafont ~~himself~~ on the basis of the first appearance datum of *Hippotherium* (formerly *Hipparion*; Crusafont Pairó, 1950, 1951, 1953; Crusafont Pairó and Truyols Santonja, 1960). The second explanation, in contrast, remained a reasonable hypothesis that would be falsified by

~~the find of~~ *Hippotherium* remains from the main Castell de Barberà fossiliferous ~~level~~ layer~~of CB~~. ~~Of course, t~~There is a third possible explanation, namely~~,~~ that Castell de Barberà~~CB~~ could be Vallesian in age, even if *Hippotherium* was ~~real~~ scarce or ~~even~~ absent ~~from there~~.

For many years and up to the present, most subsequent authors favored a correlation of Castell de Barberà~~CB~~ with the late Aragonian (Moyà-Solà, 1983; Agustí et al., 1985, 2001, 2013; Moyà-Solà et al., 1990; Begun, 2002a; van den Hoek Ostende and Furió, 2005; Alba et al., 2006, 2010, 2011; Casanovas i Vilar, 2007; Casanovas-Vilar et al., 2008, 2011a; Robles et al., 2010; Almécija et al., 2011; Sukselainen et al., 2015; Agustí, 2018). The various alternate possibilities discussed ~~in the paragraph~~ above were generally not discussed further, or ~~at most~~ were dismissed on the grounds that the specimen ~~would had been~~was purportedly washed down from upper layer~~evel~~s of the outcrop~~ping~~ section (e.g., Santafé Llopis, 1978; van den Hoek Ostende and Furió, 2005; Casanovas i Vilar, 2007; Alba et al., 2011). However, it should be taken into account that the uppermost ~~levels~~ layers are ~~very~~ close (<10 m) to the main fossiliferous ~~level~~ layer of Castell de Barberà~~CB~~ (Casanovas-Vilar et al., 2016b). The relatively short stratigraphic distance (110 m, according to Crusafont Pairó and Truyols Santonja, 1951) between Castell de Barberà~~CB~~ and Can Llobateres 1 (with an interpolated age of 9.76 Ma; Casanovas-Vilar et al., 2016b ~~(110 m, according to Crusafont Pairó and Truyols Santonja, 1951~~) also ~~further~~ adds difficulty to~~contradicts~~ the considerable age difference estimated between the two localities (Alba and Moyà-Solà, 2012; Casanovas-Vilar et al., 2014)—which would require ~~hypothesizing~~ the existence of ~~considerable~~ major faults (e.g., Agustí et al., 1985) that~~, albeit conceivable,~~ have yet to be documented. ~~Not surprisingly,~~S~~ s~~ome authors remained open to~~about~~ (Aguilar et al., 1979; Ginsburg, 1986), or even supported (Gibert, 1975; de Bruijn et al., 1992; Andrews et al., 1996), an alternate correlation of Castell de Barberà~~CB~~ with MN9. However, it was not until ~~the~~ publication of a *Hippotherium* lower molar ~~of *Hippotherium*~~ discovered among the ~~classical~~ museum collections of Castell de Barberà~~CB~~ (Rotgers and Alba, 2011) that most authors started to favor a Vallesian age for the site (Casanovas-Vilar et al., 2011b, 2014, 2016a,b; Alba, 2012; Alba and Moyà-Solà, 2012; Almécija et al., 2012; Robles et al., 2013a,b; Furió et al., 2015; Villa et al., 2017). Casanovas-Vilar et al. (2014) even estimated an age of 10.55 Ma for the site ~~on the~~ based~~is~~ of the stratigraphic distance between Castell de Barberà~~CB~~ and Can Llobateres reported by Crusafont Pairó and Truyols Santonja (1951). ~~Later on,~~ Casanovas-Vilar et al. (2016a,b) then correlated Castell de Barberà~~CB~~ to the *Hippotherium* – *Cricetulodon hartenbergeri* interval subzone (11.88–10.3 Ma) of the Vallès-Penedès Basin without further specifying its age. However, these authors considered that such a correlation, which has yet to gain universal acceptance (e.g., Agustí et al., 2013; Sukselainen et al., 2015; Agustí, 2018), must be considered tentative—given ~~the~~ uncertainties about the exact provenance of the *Hippotherium* remains from Castell de Barberà~~CB~~, which would still allow ~~for~~ a latest Aragonian age for~~of~~ the main fossiliferous ~~site~~layer.

With the aim of~~to~~ performing magnetostratigraphic analyses ~~that could~~to more conclusively settle ~~this issue~~the age of the Castell de Barberà sequence and hopefully lead to the find of additional fossils, a team from the ICP led by author7 and author6 planned to reopen the ~~site of~~ Castell de Barberà~~CB~~ site in 2014. ~~This fieldwork initiative~~Finding the exact location of the site was hampered by the vagueness of published indications ~~about the site's exact location~~ (Crusafont-Pairó and Golpe, 1972; Golpe Posse, 1974), coupled with decades of vegetation growth and recent anthropic modifications ~~of the river bank~~ (to ~~build a roadway in~~enlarge the ~~framework~~

of a riverbank's trackwayine park). Finally,T two paleontological campaigns were performed there in 2014 and 2015 with the aid of an excavator machine (Fig. 2). Excavations in 2014 were focused on a Miocene section (Ssection 1, or Castell de Barberà s.l.) situated less than 300 m from the classical original outcrop (Ssection 2, or Castell de Barberà s.s.), which was excavated in 2015. The exact geographic and stratigraphic situation of the classical original main fossiliferous level layer in Ssection 2 was located thanks to the collaboration of the late Josep V. Santafé, who had repeatedly excavated at the site during the 1970s with Crusafont, and indicated the exact location while visiting the site during the 2015 season. Although our works confirmsed that the bone accumulation of the main Castell de Barberà fossiliferous level layerof CB is exhausted, they enabled the recovery ofwe recovered additional fossil remains from the same layer and other layers, and tookas well as the paleomagnetic samplesing of from the two excavated sections. In tThis paper, aims towe report the magnetostratigraphic data, and, with the aid of biostratigraphic considerations, provide a more accurate dating of Castell de BarberàCB and discuss its implications for Miocene hominoid and pliopithecoid evolution during the Miocene (for a preliminary report of these data, see Alba et al., 2018a,b).

## 2. Materials and methods

*2.1. Location and stratigraphy of Castell de Barberà*

From a geological viewpoint (Fig. 3), Castell de BarberàCB is located on the distal facies of the Castellar del Vallès aAlluvial fFan sSystem, which belong to the middle to late Miocene uUpper cContinental cComplexes of the Vallès-Penedès Basin in (NE Iberian Peninsula (Agustí et al., 1985; Garcés, 1995; de Gibert and Casanovas-Vilar, 2011). These outcropping sediments mostly consist of mudstones (especially siltsones and some finer claystones) with ~~some~~ intercalated coarse to fine sandstones (Santafé Llopis, 1978). The repeated alternation of these lithologies along the stratigraphic series may be interpreted as energy cycles—from higher energy at the base of each cycle, where sandstones are more abundant, to lower energy toward the top, where fine siltstones and claystones ~~are~~were deposited.

~~To better interpret the paleomagnetic data, we also provide an updated faunal list of the rodent assemblage from CB, which includes the material recovered in 2014–2015. Given its biostratigraphic significance, we further review the few hipparionin remains from the site, including a distal humeral fragment (IPS87652) that was found in 2015. All the fossils are housed at the ICP.~~ Most of the specimens from the ~~classical~~ collections of Castell de Barberà (mostly amassed between 1965–1981) lack ~~any kind of~~ associated information. When preserved, some old field labels refer to ‘layer 1’, and more sporadically to a so-called ‘higher layer’. ~~In~~ Despite ~~of~~ this, it is possible to confidently assert that most of the ~~classical~~ material came from a single layer (Santafé Llopis, 1978), which according to J.V. Santafé (pers. comm. to author6 and author7) was stratigraphically equivalent to layer CB-D excavated in 2015 (Fig. 2B). Santafé Llopis (1978) provided coordinates for the site (31N 428291 E – 4597272 N), indicating that it would be situated close to Ca n’Altimira. However, the published coordinates are at odds with the description of the site~~’s~~ location, and that confirmed by Santafé i~~o~~n the field is ~~indeed~~ situated more than 400 m southward (31N 428314 E – 4596862 N; Fig. 2A)[1].

[1] Geographic coordinates are given in the Universal Transverse Mercator – European Terrestrial Reference System 1989 (UTM ETRS89). They were verified ~~with the aid~~

~~From a geological viewpoint (Fig. 3), CB is located on the distal facies of the Castellar del Vallès Alluvial Fan System, which belong to the middle to late Miocene Upper Continental Complexes of the Vallès-Penedès Basin (NE Iberian Peninsula). These outcropping sediments mostly consist of mudstones (especially siltsones and some finer claystones) with some intercalated coarse to fine sandstones (Santafé Llopis, 1978). The repeated alternation of these lithologies along the stratigraphic series may be interpreted as energy cycles—from higher energy at the base of each cycle, where sandstones are more abundant, to lower energy toward the top, where fine siltstones and claystones are deposited.~~

Two magnetostratigraphic sections, located along the left bank of the Ripoll River and ~~generated~~ exposed with the aid of digging machinery, were sampled for this study (Figs. 2A and 4): S~~s~~ection 1 was excavated in 2014 close to Ca n'Altimira (bottom: 31 N 428232 E – 4597224 N), ~~whereas~~ and S~~s~~ection 2 was excavated in 2015 ~~in the location of~~at the ~~classical~~ original outcrop (bottom: 31N 428316 E – 4596888 N). The horizontal distance between the two points is 346 m. Strata ~~gently~~ dip gently toward the east~~E~~, and altitude differences ~~in altitude~~ between the two points are negligible (both are~~, both being~~ situated ~~~only minimally higher than~~ 95 m above sea level). Both sections (Supplementary Online Material [SOM] S1 and Fig. S1) were correlated on lithostratigraphic grounds ~~and~~ based on the assumption that there is no major fault located between the two sections. In particular, ~~by taking into account~~considering a bedding~~n~~ orientation ~~of beds~~ of 002/10E (strike/dip), measured in ~~the~~ outcropping layers ~~of~~ in both sections, the bottom of magnetostratigraphic

~~of~~using topographic maps and orthophotos from the web application VISSIR v3.26 of the Institut Cartogràfic i Geològic de Catalunya (ICGC, 2018).

S~~s~~ection 1 would be stratigraphically situated 16.6 m below the bottom of S~~s~~ection 2. Given that S~~s~~ection 1 has a thickness of almost 50 m and S~~s~~ection 2 of about 20 m, these results imply that, unless there is a fault between the two sections, they must overlap to a large extent (SOM Fig. S1). Such correlation methodology is far from ideal, not only because it has to assume the lack of major faulting, but also because it does not take into account lateral changes in lithology and local accumulation rates. However, such an approach was unavoidable given the dense vegetation cover between the two sections and the impossibility to deforest the whole riverbank in between.

*2.2. Paleomagnetism and biostratigraphy*

-A total of 25 samples from 14 magnetostratigraphic sites were collected along the ~50 m-thick S~~s~~ection 1, although most ~~of the~~ samples ~~were~~ are concentrated i~~o~~n the lower portion (~20 m in thickness) of the section. ~~In turn~~Also, 22 samples from 11 sites were collected along the 20 m-thick S~~s~~ection 2. No further samples were taken ~~in the area~~ due to the presence of unsuitable coarse-grained lithologies and the inaccessibility of ~~the remaining~~other outcrops.

All samples were subjected to stepwise thermal demagnetization (Fig. 4) ~~aiming~~ to isolate the ~~different~~ paleomagnetic components contributing to the n~~N~~atural r~~R~~emanent m~~M~~agnetization (NRM). Temperature increments of 50~~º~~ to 30 °C~~º~~ were applied up to complete demagnetization of the samples ~~of the NRM~~ or to temperatures at which acquisition of spurious magnetization caused ~~observation of~~ unstable behavior ~~caused by neoformation of magnetite upon heating~~. Maximum unblocking temperatures close to 600 ~~º~~°C indicate that the magnetic remanence is carried by iron oxides. In earlier studies ~~in~~ of these ~~same~~ sedimentary sequences

(Garcés et al., 1996), detrital magnetite has been reported as the main remanence carrier~~ of the remanence~~, together with pigmentary and detrital hematite.

Stepwise demagnetization reveal~~e~~s~~d~~ the presence of a stable magnetic component at temperatures above 250 °~~º~~C, which~~ could~~ demagnetizes at temperatures up to about 600 °~~º~~C. A characteristic ~~direction of the~~ magnetization direction was calculated by means of least~~-~~-squares analysis for each sample (Kirschvink, 1980). Complete demagnetization could rarely~~not~~ be achieved, as~~ when~~ thermal treatment often le~~a~~d to the acquisition of a spurious remanence ~~at temperatures~~ above 400 °~~º~~C~~. This was~~ likely related to chemical alteration of Fe-bearing minerals ~~upon heating~~ and growth of new magnetite upon heating. ~~In these cases, if~~Fortunately, the direction of the magnetic remanence often remained stable between 250 and 400 °~~º~~C~~ remained stable~~, and a paleomagnetic ~~average~~ direction ~~was~~ could be calculated from this temperature range. Anchoring the solutions to the origin was needed in most of cases as a clean progressive decay of the remanence could not often be observed (Fig. 4). A total of 47 paleomagnetic directions were obtained (SOM Table S1) and were ranked into three quality categories. Q1 directions (9 samples) were obtained from samples showing a gradual and nearly complete decay towards the origin. Q2 directions (32 samples) were obtained from samples that underwent unstable behavior at temperatures typically above 400 °C. Q3 directions (6 samples) were obtained from samples that underwent unstable at temperatures lower than 400 °C and did not show a clear decay of its remanence upon heating, and were not considered for polarity interpretation.

A polarity interpretation of the paleomagnetic directions was done by calculating the latitude of the v~~V~~irtual g~~G~~eomagnetic p~~P~~ole (VGP) for eac~~at~~h sample~~ level~~. Positive and negative VGP latitudes correspond~~ed~~ to normal and reversed polarity, respectively (Fig. 4).

To aid better interpretation of the paleomagnetic data, we also provide an updated faunal list of the rodent assemblage from Castell de BarberàCB, which includes the material recovered in 2014–2015. Given its biostratigraphic significance, we further review the few hipparionin remains from the site, including a distal humeral fragment (IPS87652) that was found in 2015. All the fossils are housed at the ICP.

## 3. Results

### *3.1. Rodent biostratigraphy*

The scanty reports of rodents in the intial faunal lists from CB (Crusafont-Pairó and Golpe, 1972; Crusafont-Pairó and Casanovas Cladellas, 1973; Crusafont-Pairó and Golpe-Posse, 1974; Golpe-Posse, 1974) were soon followed by a detailed study (Aguilar et al., 1979) that recognized four cricetids and five glirids. After multiple additions and refinements (Agustí, 1981; Agustí et al., 1985; Aldana Carrasco, 1992a,b,c; Casanovas i Vilar, 2007), the most recently published list is that of Casanovas-Vilar et al. (2016b), with up to 16 species. According to our own revision of the material, the classical rodent assemblage from Castell de Barberà, composed of 785 identifiable rodent remains, records up to 16 species, plus four additional ones recognized on the basis of the material recovered in 2015 (Table 1).

### *3.2. Presence of* Hippotherium

It is uncertain on the basis of what specimen Crusafont-Pairó and Golpe-Posse (1974) originally reported the presence of *Hipparion* (currently, *Hippotherium*) at CB. However, Rotgers and Alba (2011) reported and figured an $M_3$ (IPS57437) of *Hippotherium* found among the CB collections. The possibility that the specimen's provenance was misrecorded is unlikely, given the fact that during a recent revision of the collections we were able to find a $dP^2$ germ (IPS92389) also attributable to this taxon. While the exact stratigraphic provenance of these remains is not recorded, during the 2015 field season we recovered from level D a distal humeral fragment (IPS87652) of an equid (Fig. 4A) that is virtually undistinguishable in both size and shape from Vallesian specimens of *Hippotherium* from Vallesian the same basin (Fig. 4B, C). The taxonomic attribution of IPS87652 to *Hippotherium* is complicated by the fact that both anchitheriine and hipparionin equids co-occur in some early Vallesian localities of the Iberian Peninsula and elsewhere in Europe (Salesa et al., 2004; Daxner-Höck and Bernor, 2009; Rotgers and Alba, 2011; Bernor et al., 2017). Although IPS87652 is broken in several fragments, the preserved portion of the distal diaphysis and epiphysis enable taxonomically meaningful morphological comparisons, which are provided below given the biostratigraphic relevance of *Hippotherium*.

In terms of size, IPS87652 fits well with *Hippotherium* (*primigenium*) humeri from elsewhere in Europe, as measured by the mediolateral width of the distal epiphysis (70.0 mm), which is well within the range of the Höwenegg (MN9, Germany) sample of *Hippotherium primigenium* ($\bar{X}$ = 70.5 mm, range = 65.3–74.1 mm, *n* = 13; Bernor et al., 1997:Table 6.2). In contrast, the size of the specimen rules out an assignment to any species of *Anchitherium* from the Iberian Peninsula (and elsewhere in Europe), which are clearly smaller (Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011). On size grounds, IPS87652 would only be consistent with the much larger anchitheriine *Sinohippus sampelayoi* (formerly in *Anchitherium*), which is recorded at Nombrevilla 1 (MN9) in Spain (Salesa et al., 2004). Nonetheless, the latter species has not been recorded in the Vallès-Penedès Basin, where available anchitheriine remains from both the late Aragonian (Abocador de Can Mata) and

~~early Vallesian (Can Poncic 1) indicate a much smaller size (Crusafont-Pairó and Golpe-Posse, 1974; Crusafont-Pairó, 1976; Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011).~~

~~Furthermore, on qualitative morphological grounds IPS87652 also more closely resembles *Hippotherium* than anchitheriines. The most relevant features include (author6, pers. obs.): (i) the presence of a narrow but deep groove, medial to the lateral epicondyle and separated by the lateral surface of the radial fossa, that marks the extensive origin attachment of the extensor digitorum communis muscle (Bernor et al., 1997); and (ii) a larger (wider and higher) trochlea relative to the smaller (narrower and lower) capitulum. The aforementioned crest (i) is much deeper in *Hippotherium* than in anchitheriines—where it is absent or only weakly expressed, and only the lateral epicondylar crest can be clearly observed. In turn, the latter feature (ii) is characteristic of *Hippotherium*, but absent from *Anchitherium*, where the capitulum is larger than the trochlea. Overall, both size and morphology support a confident assignment of IPS87652 to *Hippotherium*, in further agreement with the scarce dental material of this taxon previously reported from CB (Rotgers and Alba, 2011).~~

### *3.1~~3~~. Magnetostratigraphy*

~~The results of~~O ~~o~~ur paleomagnetic ~~analyses~~ results (Fig. 5) indicate that at least four magnetozones are recorded in S~~s~~ection 1 (beginning with a reversed polarity one), whereas two magnetozones are recorded in S~~s~~ection 2 (beginning with a normal polarity magnetozone, in which ~~the classical fossiliferous level~~ CB-D is situated). The stratigraphic distance of ca. 17 m between the bases of the two sections would suggest that six ~~different~~ magnetozones have been sampled (Fig. 6), with the first normal polarity magnetozone of Ssection 2 (i.e., that of the classical original main fossiliferous levellayer) being correlated with the second normal polarity magnetozone of Ssection 1 (N2), and with the reversed polarity magnetozone of Ssection 2 (R3) not having been sampled in Ssection 1. Given the close distance between the two sections, local differences in accumulation rate differencess are negligible. However, some uncertainties remain, because it isdue to the impossibleility to completely dismiss discount the potential presence of one or more small faults between the two sections, thus allowing for other (even if less likely) alternate correlations. Thus,A assuming that both sections completely overlap, it might be conceivable to correlate the first normal polarity magnetozone of Ssection 2 with the first normal polarity one of Ssection 1, which resultsing in only four different magnetozones. Other possible correlations, involving only a partial overlap between the two sections, would imply up to five different magnetozones, with the normal polarity magnetozone of Ssection 2 being older than the wholeall of Ssection 1 or, alternatively, with the normal polarity magnetozone of Ssection 2 being correlated with the uppermost portion of Ssection 1.

### *3.21. Rodent biostratigraphy*

The Sscanty reports of rodents in the intial faunal lists from Castell de BarberàCB (Crusafont-Pairó and Golpe, 1972; Crusafont-Pairó and Casanovas Cladellas, 1973; Crusafont-Pairó and Golpe-Posse, 1974; Golpe-Posse, 1974) were soon followed by a detailed study (Aguilar et al., 1979) that recognized four cricetids and five glirids. After multiple additions and refinements (Agustí, 1981; Agustí et al., 1985; Aldana Carrasco, 1992a,b,c; Casanovas i Vilar, 2007), the most recently published list is that of Casanovas-Vilar et al. (2016b), with up to 16 species. According to our own taxonomic revision of the material, the classicalpreviously collected Castell de Barberà rodent assemblage from Castell de Barberà, which is composed of 785 identifiable rodent remains, records up to 16 species, plus four additional ones recognized on the basis of the material recovered in 2015 (Table 1).

*3.32. Presence of* Hippotherium

It is uncertain on the basis of what specimen Crusafont-Pairó and Golpe-Posse (1974) originally reported the presence ofidentified as *Hipparion* (currently, *Hippotherium*) at Castell de BarberàCB. However, Rotgers and Alba (2011) reported and figured an $M_3$ (IPS57437) of *Hippotherium* $M_3$ (IPS57437) found amongfrom the Castell de BarberàCB collections. The possibility that the specimen'sof a misrecorded provenance was misrecorded is unlikely given that, the specimen was clearly labeled. given the fact that dIn oururing a recent revisionre-examination of the large mammal collections, we were able to findalso found a $dP^2$ germ (IPS92389) also attributable to this taxon. Crusafont-Pairó and Golpe-Posse (1974) did not figure or describe the specimen attributed by them to *Hippotherium*, but merely referred to it as a somewhat rounded fragment—which might apply to the above-mentioned deciduous premolar, although it is not possible to be certain. While the exact stratigraphic provenance of these remains is not recorded, even if they both came from the upper layer they would still be relevant for interpreting the magnetostratigraphic results, indicating a Vallesian age for at least the topmost portion of the section.

Moreover, during the 2015 field season we recovered from levelCB--D during the 2015 field season a distal humeral fragment (IPS87652) of an equid (Fig. 74A) that is virtually iundistinguishable in both size and shape from Vallesian specimens of *Hippotherium* specimens from Vallesian the same basin (Fig. 74B, C). The taxonomic attribution of IPS87652 to *Hippotherium* is complicated by the fact that both anchitheriine and hipparionin equids co-occur in some Iberian early Vallesian localities ~~of the Iberian Peninsula~~ and elsewhere in Europe (Salesa et al., 2004; Daxner-Höck and Bernor, 2009; Rotgers and Alba, 2011; Bernor et al., 2017). Although IPS87652 is ~~broken in several~~ fragmentarys, the preserved portion of the distal diaphysis and epiphysis enable taxonomically meaningful morphological comparisons, which are provided below given the biostratigraphic relevance of *Hippotherium*.

In terms of size, IPS87652 fits well with *Hippotherium* (*primigenium*) humeri from elsewhere in Europe, as measured by the mediolateral width of the distal epiphysis (70.0 mm), which is well within the range of the Höwenegg (MN9, Germany) sample of *Hippotherium primigenium* ($\bar{X}$ = 70.5 mm, range = 65.3–74.1 mm, $n$ = 13; Bernor et al., 1997: Table 6.2). In contrast, the size of the specimen rules out an ~~assignment~~attribution to any ~~species of~~ *Anchitherium* species from the Iberian Peninsula (and elsewhere in Europe), which are ~~clearly~~ smaller (Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011). On size grounds, IPS87652 would only be consistent with the much larger anchitheriine *Sinohippus sampelayoi* (formerly in *Anchitherium*), which is recorded at Nombrevilla 1 (MN9) in Spain (Salesa et al., 2004). Nonetheless, the latter species has not been recorded in the Vallès-Penedès Basin, where available anchitheriine remains from both the late Aragonian (Abocador de Can Mata) and early Vallesian (Can Poncic 1) indicate a much smaller size (Crusafont-Pairó and Golpe-Posse, 1974; Crusafont-Pairó, 1976; Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011).

Furthermore, on qualitative morphological grounds IPS87652 also more closely resembles *Hippotherium* than anchitheriines. The most relevant features~~-~~ is the larger trochlea relative to the smaller capitulum. In particular, IPS87652 resembles *Hippotherium* in the mediolaterally wide and cylindrical trochlea and proximodistally short capitulum, in contrast to the mediolaterally narrower and more globular trochlea and longer capitulum of anchitheriines (MacFadden, 2001). Therefore, the distal articular surface of IPS87652 is clearly *Hippotherium*-like and distinct from the more primitive pattern displayed by anchitheriines (SOM Fig. S2). Moreover, ~~include (author6, pers. obs.): (i) the presence of a narrow but deep groove,~~ medial to the lateral epicondyle ~~and~~ (between ~~separated by~~ the lateral surface of the radial fossa and the lateral epicondylar crest), IPS87652 posseses a narrow but deep groove that marks the extensive origin attachment of the extensor digitorum communis muscle (Bernor et al., 1997). This feature is consistently present in the *Hippotherium* sample from Höwenegg (Bernor et al., 1997) but absent or weakly developed in ~~; and (ii) a larger (wider and higher) trochlea relative to the smaller (narrower and lower) capitulum. The aforementioned crest (i) is much deeper in *Hippotherium* than in~~ anchitheriines (SOM Fig. S2)~~—where it is absent or only weakly expressed, and only the lateral epicondylar crest can be clearly observed. In turn, the latter feature (ii) is characteristic of *Hippotherium*, but absent from *Anchitherium*, where the capitulum is larger than the trochlea.~~ Overall, both size and ~~morphology~~shape support a confident assignment of IPS87652 to *Hippotherium*, in ~~further~~ agreement with ~~the~~ scarce dental material of this taxon previously reported from Castell de Barberà~~CB~~ (Rotgers and Alba, 2011).

## 4. Discussion

### *4.1. Biochronology*

Among Miocene terrestrial assemblages, rodents are generally ~~of utmost~~greatly significan~~ce~~t for ~~providing an~~ accurate dating of fossil sites, even when magnetostratigraphic data are available. This is because paleomagnetism only provides a binary signal, whose interpretation critically relies on independent constraints. In the Vallès-Penedès Basin, a revised scheme of local biozones and subzones largely based on rodents was recently provided by Casanovas-Vilar et al. (2016b)~~, being mostly based on rodents~~. The only (but most remarkable) exception in this regard ~~refers to~~concerns the Aragonian/Vallesian boundary, which is defined by the first appearance datum of the equid *Hippotherium*. This is because the beginning of the Vallesian was not accompanied by important changes in the rodent faunas (Agustí et al., 1997, 2001). Therefore, according to Casanovas-Vilar et al. (2016b), the latest Aragonian ~~would~~ corresponds to the *Democricetodon crusafonti – Hippotherium* interval subzone (MN7+8, 11.88–11.18 Ma), whereas the earliest Vallesian ~~would~~ corresponds to the *Hippotherium – Cricetulodon hartenbergeri* interval local subzone (MN9, 11.18–10.3 Ma)[2]. ~~In the case of~~For Castell de Barberà~~CB~~, the most significant datum provided by ~~the~~ rodents ~~assemblage~~ is the lack of *Cricetulodon*, which precludes ~~a~~ correlation with the *Cricetulodon hartenbergeri* range subzone (MN9, 10.3–9.98 Ma)~~,~~ and ~~thus conclusively~~ indicates conclusively an age older than 10.3 Ma. Otherwise, however, the rodent assemblage is consistent with both a late Aragonian or early Vallesian age. In contrast, the presence of

[2] Interval zones are defined by two specified biohorizons (in these cases, corresponding to the lowest occurrences of the specified taxa), and termed with the name of the taxon defining the basal boundary preceding that of the taxon defining the top boundary (Murphy and Salvador, 1999).

*Hippotherium* at Castell de Barberà~~CB~~ (Fig. 7~~4~~A) implies—by definition—a post-Aragonian age.

Given the restricted evidence provided by the rodent faunas ~~about~~ at Castell de Barberà, Casanovas-~~-~~Vilar et al. (2014, 2016a, b) favored a correlation of this site with the earliest Vallesian mostly based on the presence of hipparionins, even if they did so tentatively, given ~~the~~ uncertainties about the provenance of ~~the~~ scarce available material. Although the record~~find~~ of *Hippotherium* ~~remains~~ at Castell de Barberà~~CB~~ was already reported by Crusafont-Pairó and Golpe-Posse (1974), most later authors dismissed its biochronological significance~~,~~ by arguing that the specimen came from a layer ~~situated~~ above the main ~~classical~~ fossiliferous ~~level~~layer. ~~Indeed,~~O ~~o~~ur revision of the ~~classical~~ museum collections indicates that *Hippotherium* is recorded at Castell de Barberà~~CB~~ by two dental specimens. Even if both teeth came from a stratigraphically higher layer, these remains would indicate, at ~~the very~~ least (given the thickness of the outcrop~~ping~~ section), that the main fossiliferous ~~level~~ layer would be situated less than 10 m below unambiguously Vallesian layer~~evel~~s. ~~The~~ L~~l~~ongstanding discussion about the exact stratigraphic provenance of the material is now irrelevant after the find of the distal humeral fragment of *Hippotherium* reported in this paper, from a layer stratigraphically equivalent to the ~~classical~~ original main fossiliferous ~~level~~layer. This find settles this issue~~,~~ by ~~unambiguously~~ indicating unambiguously that Castell de Barberà~~CB~~ is Vallesian in age, even if a large portion of the rest of the fauna is still reminiscent of ~~that from~~ the late Aragonian.

The first appearance datum of *Hippotherium* in the Vallès-Penedès Basin is currently dated to 11.18 Ma, based on magnetostratigraphic correlation of the section in which Creu de Conill 20 (CCN20) is situated (Garcés et al., 1997; Agustí et al., 1997; Casanovas-Vilar et al., 2016a,b). The taxonomic identity of the earliest hipparionins from the Vallès-Penedès Basin is uncertain, ~~in~~ partly due to the lack of diagnostic material and also because the alpha-taxonomy of *Hippotherium* is yet to be ~~conclusively~~ settled conclusively—particularly with regard to the earliest representatives of the genus (e.g., Bernor et al., 2017). Some authors have considered that the type species of the genus, *H. primigenium*, is a single polymorphic species with many regional variants (Pesquero and Arribas, 2002; Zouhri and Bensalmia, 2005). However, ~~here~~ we follow Bernor et al. (1996) in recognizing that *H. primigenium* is best considered a species complex, which may be formally designated as *Hippotherium* (*primigenium*) spp.[3] The nominal species *Hippotherium catalaunicum*, erected by Pirlot (1956) based on material from ~~the~~ els Hostalets de Pierola, is available for the Vallesian *Hippotherium* remains from the Vallès-Penedès Basin. This species has been considered a junior subjective synonym of *Hippotherium primigenium* by several authors (Forstén, 1968, 1978; Alberdi, 1972; Pesquero and Arribas, 2002; Zouhri and Bensalmia, 2005), but here we follow Bernor and colleagues (Bernor et al., 1996; Bernor and Armour-Chelu, 1999) in accepting a distinct species status for this taxon within the *Hippotherium primigenium* complex—i.e., *Hippotherium* (*primigenium*) *catalaunicum*. Nevertheless, we refrain from attributing the ~~CB~~ scanty Castell de Barberà specimens to this species~~,~~ because they do not allow to ~~ascertain~~ assess its purportedly derived distinguishing features from *Hippotherium primigenium* s.s. (namely, a very elongate and anteroposteriorly oriented preorbital fossa; Bernor et al., 1996).

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[3] The parentheses around the epithet denote a supraspecific species-group taxon, such as a species group or superspecies (see ICZN, 1999: Art. 6.2)

Pending a more detailed study, caution in~~ the~~ taxonomic assignment of the *Hippotherium* remains from Castell de Barberà~~CB~~ is further advised by the plesiomorphic dental morphology ~~displayed by~~of the earliest *Hippotherium* samples from elsewhere in Europe (see below). In the Vallès-Penedès Basin, the interpolated age of ~~CCN20~~ Creu de Conill 20 fits well with that of the earliest Vallesian hipparonins from Pannonian C (ca. 11.4–11.0 Ma) localities (Atzelsdorf and Gaiselberg) of the Vienna Basin, Austria (Woodburne, 2007, 2009; Bernor et al., 2017), which are as yet unassigned to species and appear more plesiomorphic than *H. primigenium* from the type locality (Eppelsheim) and other Central European localities. These earliest hipparionins from Europe most closely resemble *Cormohipparion* sp. from the earliest late Miocene (ca. 11.5 Ma) of North America (Woodburne, 2005, 2007), and suggest that *Hippotherium* is the descendant of a single dispersal event of *Cormohipparion* from North America into Eurasia sometime after 11.5 Ma (Woodburne, 2009; Bernor et al., 2017). According to Harzhauser (2009), Atzelsdorf would be ca. 11.2–11.1 Ma in age—i.e., roughly coeval to Creu de ~~CN20~~Conill 20—whereas elsewhere in the Iberian Peninsula ~~the dispersal of~~ *Hippotherium* dispersal is not documented until somewhat later (within C5n.2n, ca. 10.8–10.7 Ma) in the Calatayud-Daroca Basin (Garcés et al., 2003).

With regard to the biostratigraphic significance of the lack of *Hippotherium*, it should be ~~taken into account~~considered that, as illustrated by some Vallès-Penedès sites, this taxon may be ~~quite~~ rare during the earliest Vallesian. This is best illustrated by the local section of Ecoparc de Can Mata, where *Hippotherium* has yet to be recorded de~~in~~ spite ~~of~~ being stratigraphically situated above the Aragonian/Vallesian transition—as indicated by litho-, magneto-, and rodent biostratigraphic data (Alba et al., 2012; Casanovas-Vilar et al., 2016b). Therefore, c~~C~~aution is ~~therefore~~ required when inferring the age of other sites chronologically close to the Aragonian/Vallesian boundary~~,~~ because the absence of *Hippotherium* does not necessarily imply a pre-Vallesian age (e.g., Can Missert; see discussion in Robles et al., 2011; contra Agustí et al., 2005)—~~being~~ and is alternatively attributable to ecological conditions (e.g., unsuitable local habitat) and/or taphonomic factors (i.e., sampling bias~~es~~). Equating the lack of *Hippotherium* with a late Aragonian age ~~is the reasoning that~~ originally led to the misdating of Castell de Barberà~~CB~~, and this reasoning has been ~~being~~ further perpetuated ~~afterward in~~de spite ~~of~~ clear (even if scarce) evidence that *Hippotherium* was recorded at least somewhere within the short section where the site is located.

When both rodents and *Hippotherium* are considered together, biostratigraphic data enable ~~an~~ unambiguous correlation of Castell de Barberà~~CB~~ with the *Hippotherium* – *Cricetulodon hartenbergeri* interval local subzone (11.18–10.3 Ma; Fig. 6), as previously supported by Casanovas-Vilar et al. (2016a, b) on tentative grounds.

### *4.2. Magnetostratigraphy*

The magnetostratigraphic data reported in this paper ~~further~~ enable ~~a~~ more accurate dating of Castell de Barberà~~CB~~ within the early Vallesian, even if the shortness of the sampled sections allows ~~for~~ several possible interpretations. The most parsimonious interpretation, based exclusively on the stratigraphic distance between the two sections as computed from dip measurements, implies as much as six ~~different~~ magnetozones. Other interpretations imply four to five ~~different~~ magnetozones. Irrespective of the preferred interpretation, regarding ~~the~~ correlation of the ~~sampled~~ identified magnetozones with the GPTS (Ogg ~~et al.~~, 2012), ~~there are~~ two important factors should~~to~~ be considered. First, the ~~classical~~ main fossiliferous ~~level~~ layer of

Castell de Barberà~~CB~~ is situated in a normal polarity magnetozone. Second, no matter what correlation between the two sections is preferred, there are at least four ~~different~~ magnetozones within a short ~~sequence of~~ 50–80 m sequence~~in thickness~~. Taking into account an average sedimentation rate of ~20 cm/kyr, computed for both the Vallesian (Garcés et al., 1996) and the late Aragonian (Alba et al., 2017) of the Vallès-Penedès Basin, the sampled interval would not represent more than 400 kyr. The frequent alternation of normal and reversed polarity magnetozones in the composite sequence of Castell de Barberà indicates that ~~is excludes the correlation of any of the sampled normal magnetozones with~~ the long normal subchron C5n.2n that is characteristic of the early Vallesian is not recorded in the sampled interval. Only the uppermost normal polarity magnetozone N3 could correlate with the base of C5n.2n. The magnetostratigraphic results rather ~~—except, perhaps, for the uppermost part of the sampled composite sequence—and~~ suggests ~~instead~~ that most of the composite sequence ~~must be~~ correlatesd with the ~~latest Aragonian and earliest Vallesian~~upper C5r, where multiple reversals are recorded overin a short time interval (Ogg~~ et al.~~, 2012).

An alternate correlation of the reversed polarity magnetozones R2 and R3 with some cryptochrons or geomagnetic excursions within C5n.2n (Cande and Kent, 1992; Roberts and Lewin-Harris, 2000; Evans et al., 2007) is considered unlikely because of the short duration, possibly less than 10 kyr, of these events. While chances of recording such short geomagnetic features in fluvial sediments are typically low, to record as many reversed polarity directions as normal polarity directions within C5n.2n is considered implausible. The fact that all the reversed polarity magnetozones documented at Castell de Barberà are recorded by more than a single paleomagnetic sample strongly argues against any of them representing a short-lived excursion event within C5n.2n. The similar thickness of the documented normal and reversed polarity magnetozones at Castell de Barberà strongly argues against this possibility, and favor a correlation of most of the sequence with chron C5r.

In our preferred interpretation (Fig. 6), the ~~first~~ lowermost normal polarity magnetozone of S~~s~~ection 1 would be correlated with subchron C5r.2r-1 (11.308–11.263 Ma), and the ~~first~~ lowermost normal polarity magnetozone of S~~s~~ection 2 (i.e., the main ~~classical~~ fossiliferous ~~level~~layer), like the second normal polarity magnetozone of S~~s~~ection 1, with C5r~~n~~.1n (11.188–11.146 Ma). According to this interpretation, the ~~classical~~ original outcrop of Castell de Barberà~~CB~~, including the main fossiliferous ~~level~~ layer at about the middle of the sequence ~~as well as~~and its uppermost ~~levels~~layers, would cover a time span approximately between 11.2 and ~~–~~ 11.1 Ma. Such a correlation would be compatible with the composite sequence recording six ~~different~~ magnetozones (with the uppermost portion of the composite sequence, recorded in S~~s~~ection 1, ~~being~~ correlated to the lowermost part of subchron C5n.2n). This correlation would be also compatible with an alternate interpretation of the composite sequence recording only four magnetozones ~~(with the top of section 2, of reverse polarity, being somewhat younger than the upper half of section 1, of normal polarity, and which would be correlated to C5n.1n). Alternatively~~, with the ~~first~~ lower normal polarity magnetozones of each section ~~might be both~~ correlated to the same subchron, either C5r.2r-1 or C5r~~n~~.1n. However,~~ a~~ correlation with the former subchron is much more unlikely~~,~~ because it would imply a first appearance datum of *Hippotherium* about 100 kyr older than previously documented in the Vallès-Penedès Basin and elsewhere in Eurasia (Garcés et al., 1997; see also above). An older age for the bottom of S~~s~~ection 2 (normal polarity) relative to that of S~~s~~ection

1 (reverse~~d~~d polarity), implying five magnetozones, would ~~similarly~~ also imply a correlation of the first normal polarity magnetozone of S~~s~~ection 2 with C5r.2r-1, ~~so that this possibility~~which is similarly unlikely.

In summary, although there are several possible interpretations about the number and correlation of ~~the~~ magnetozones recorded in the two sampled sections, the combined magnetostratigraphic and biostratigraphic data ~~clearly~~ favor ~~a~~ correlation of the ~~classical~~ main fossiliferous ~~level~~ layer of Castell de Barberà~~CB~~ with subchron C5r~~n~~.1n. An alternative correlation with the long normal polarity chron C5n.2n, which is characteristic of the early Vallesian, is precluded by the presence of a reversed polarity magnetozone at theo~~n~~ top of the ~~classical~~ main fossiliferous ~~level~~layer—unless such a reversed polarity magnetozone is interpreted to represent a cryptochron, which seems highly unlikely as discussed above. I turn, ~~, whereas a~~ correlation with the older and short normal polarity subchron ~~within~~ C5r.2r-1 is possible, but is not favored here~~,~~ because it would imply a first appearance datum of *Hippotherium* of ca. 100 kyr older than previously documented. According to our interpretation of the results, the ~~classical~~ main fossiliferous ~~level~~ layer of Castell de Barberà~~CB~~ would be roughly equivalent in age to Creu de Conill ~~CN~~20 (11.2 Ma), and both sites would represent~~ing~~ the earliest Vallesian faunas of the Vallès-Penedès Basin, with the uppermost ~~levels~~ layers of the ~~classical level~~original Castell de Barberà outcrop, which also delivered some fossil remains, being correlated with C5r.1r and with an estimated age closer to 11.1 Ma. Only ~~levels~~ layers ~~stratigraphically situated below~~underlying the ~~classical~~ main fossiliferous ~~level~~ layer might be latest Aragonian instead of earliest Vallesian, although they would be correlated with the same subchron and would have~~display~~ a similar estimated age to the nearest 0.1 Ma.

*4.3. Implications for primate evolution*

As one of the few ~~localities of the~~ European Miocene localities where pliopithecoids and hominoids are recorded, Castell de Barberà~~CB~~ is a key site for better understanding why their co-occurrence is so rare. However, ~~the~~ lack of ~~an~~ accurate dating for Castell de Barberà~~CB~~ represented a serious drawback for adequately contextualizing this~~such~~ phenomenon within the framework of faunal and paleoenvironmental changes ~~recorded at~~in the Vallès-Penedès Basin. Sukselainen et al. (2015) concluded that pliopithecoids inhabited generally more ‘humid’ environments than hominoids, and further suggested that the few localities hosting a species from~~of~~ each group might have ~~displayed~~ had even more ‘humid’ conditions than other primate-bearing ~~localities from the~~ European Miocene localities. This study relied on the hypsodonty of larger herbivorous mammals as a proxy for vegetation structure, which in turn has been used as a proxy for past humidity and precipitation (Sukselainen et al., 2015, and references therein), so that their conclusions are more adequately interpreted as indicating more closely forested conditions for primate-bearing localities (particularly those in which the two groups co-occur) as a result of higher humidity (moisture), precipitation (rainfall), or both. This interpretation is consistent~~This agrees~~ with ~~the~~ previous paleoecological analyses by Casanovas-Vilar et al. (2008), which found that Castell de Barberà~~CB~~ would have been ~~even~~ more ‘humid’ (i.e., higher moisture and/or precipitation) and displayed a more marked evergreen vegetation component than late Aragonian hominoid-bearing localities from the Vallès-Penedès Basin.

~~As far as rodents are concerned,~~ P~~exceptionally~~ articularly ‘humid’ conditions at Castell de Barberà ~~CB~~ are ~~indicated by~~consistent with the high ~~the~~ abundance of swimming castorids. They are represented by two ~~different~~ species: the small~~-sized~~ *Euroxenomys minutus*—~~indeed,~~ more than half of the rodent remains recovered using screen-washing techniques from Castell de Barberà~~CB~~ belong to this taxon—and the much rarer *Chalicomys jaegeri*, which was the size of the extant beaver (Casanovas-Vilar and Agustí, 2007; Casanovas-Vilar et al., 2008, 2010). These taxa~~, overall~~ indicat~~e~~~~ing~~ the presence of permanent water bodies ~~at the area of the site~~nearby, a~~.~~lthough not necessarily of humid and densely forested habitats. Nevertheless, in the framework of Vallès-Penedès regional setting it is consistent with the fact that Vallesian hominoids from this basin have been linked to forested humid habitats providing a year-round fruit supply (Marmi et al., 2012; Alba et al., 2018c)—such as that from Can Llobateres 1, which on the basis of plant remains has been reconstructed as a very humid marshy area with nearby dense wetland forests including some (sub)tropical elements (Marmi et al., 2012). The record of the anuran *Latonia* is also indicative of locally humid and warm conditions (Villa et al., 2017), and besides the presence of primates and beavers, a closed forested environment at Castell de Barberà is further supported by the presence of ~~In addition,~~ certain forest-dwelling taxa, such as arboreal dormice (*Bransatoglis*, *Glirudinus*, *Muscardinus*, *Myoglis*, *Paraglirulus*) and flying squirrels (*Miopetaurista* and probably *Albanensia*), which are more diverse and abundant at Castell de Barberà than in roughly contemporary sites (Casanovas-Vilar and Agustí, 2007; Casanovas-Vilar et al., 2008, 2010). Finally, certain cricetids (*Eumyarion*, *Anomalomys*) may have also preferred densely forested habitats because they tend to be more abundant in fossil faunas rich in glirids and flying squirrels (Casanovas-Vilar and Agustí, 2007).

The apparently more humid and densely forested paleoenvironmental conditions of ~~The earliest Vallesian age supported here for~~ Castell de Barberà~~CB~~ as compared to

~~indicates that this site must no longer be considered a paleoenvironmental oddity among~~ late Aragonian localities from the same basin could be explained to some extent by differences in age. However, even if the ~~, but rather the best known~~ earliest Vallesian ~~locality from the Vallès-Penedès Basin—a time span~~is not ~~very~~ well represented in ~~this basin~~theVallès-Penedès ~~and where primates are only poorly known.~~ , Castell de Barberà should not be taken as representative of ~~Interestingly, the moist paleoenvironment of CB (see also Villa et al., 2017)~~the dominant paleoenvironments in the basin as a whole during this time span—as suggested by differences in faunal composition from ~~might be at odds with~~ ~~that of~~ the roughly coeval ~~site of~~ Creu de Conill ~~CCN~~20 site, where *Hippotherium* is ~~apparently~~ more abundant (authors' unpubl. data), the micromammal assemblage indicates drier conditions (Casanovas-Vilar et al., 2006, 2008; Casanovas-Vilar and Agustí, 2007), and primates have ~~yet to~~not been recorded yet~~in spite of recent (2016–2017) fieldwork campaigns~~ (authors' unpubl. data). ~~Indeed,~~T ~~t~~he rodent assemblage from Creu de Conill ~~CN~~20 is far less diverse than that of Castell de Barberà~~CB~~ (Casanovas-Vilar et al., 2006, 2016a, b; authors' unpublished data), and includes ~~very~~ few forest-dwelling taxa (*Muscardinus*, cf. *Paraglirulus*), with beavers ~~being~~ only represented by scarce remains of *Euro~~e~~xenomys minutus*. The rodent fauna of Creu Conill 20 is overwhelmingly dominated by the cricetid *Megacricetodon ibericus*, which is very rare at Castell de Barberà and is considered to have been a generalist probably preferring more arid woodlands (Daams and Freudenthal, 1988; Casanovas-Vilar et al., 2006, 2008, 2010, Casanovas-Vilar and Agustí, 2007). At Castell de Barberà, *Eumyarion leemanni* is the most abundant cricetid, which is consistent with the occurrence of locally humid and forested environments.

The dating provided in this paper for Castell de Barberà~~CB~~ ~~clearly~~ indicates that renewed efforts are required to better characterize ~~the~~ earliest Vallesian faunas from the Vallès-Penedès Basin, not only to investigate the particular conditions that enabled ~~the~~ co-existence ~~between~~ of hominoids and pliopithecoids, but especially to ~~further~~ clarify their taxonomic status and/or phylogenetic relationships. ~~In the case of~~For pliopithecoids, *Barberapithecus huerzeleri* is exclusively known from Castell de Barberà~~CB~~ (Alba and Moyà-Solà, 2012). ~~The~~ Our results ~~of this paper enable to~~ provide an accurate dat~~eing~~ for this taxon, but additional and more complete material ~~would be~~is required to more definitively settle its crouzeliid status ~~as well as~~and its relationships with other pliopithecoid taxa. Regarding hominoids, ~~the~~ attribution of the postcranial remains from Castell de Barberà~~CB~~ to *Dryopithecus fontani* by Alba et al. (2011) was only tentative. Given that this taxon is otherwise known only from the late Aragonian of the Vallès-Penedès Basin, France and Austria (Begun, 2002b; Moyà-Solà et al., 2009; Pérez de los Ríos et al., 2013), if such assignment was confirmed then Castell de Barberà~~CB~~ might represent the last appearance datum of this genus. However, additional (especially craniodental) remains would be necessary to confirm the taxonomic status of the hominoid taxon recorded at Castell de Barberà~~CB~~, which is intermediate in time between the late Aragonian dryopithecins recorded at Abocador de Can Mata~~CM~~ and the more derived hispanopithecins recorded at the basin later during the Vallesian (Alba, 2012; Alba et al., 2017, 2018c).

Two ~~different~~ areas ~~appear most promising with regard to the prospect of finding~~of the Vallès-Penedès Basin have the potential to yield additional primate remains roughly contemporaneous with those of Castell de Barberà~~CB~~: the earliest Vallesian site of Creu de Conill ~~CN~~20 in Terrassa; and the Vallesian levels of els Hostalets de Pierola (located westward from Abocador de Can Mata; Moyà-Solà et al., 2009; Alba et al., 2017). The currently available sample of ca. 2000 macrovertebrate remains from Creu de Conill 20 is insufficient to dismiss the ulterior find of primates after additional sampling efforts at this locality (given the rarity of these taxa among Vallès-Penedès fossil assemblages), although the paleoenvironmental hints provided by the recovered fauna are not particularly promising in this regard (see above). This contrasts with the situation in the fossiliferous area of els Hostalets de Pierola, where ~~While primates have yet to be found at the Creu de Conill area,~~ the presence of an indeterminate dryopithecine is documented close to the Aragonian/Vallesian boundary ~~is documented at els Hostalets de Pierola, being recorded~~ by a female lower canine~~$C_1$~~ from the latest Aragonian ~~site~~ fossil locality of Can Mata 1 (Crusafont-Pairó and Golpe-Posse, 1973; ~~1~~Golpe Posse, 1982, 1993; Alba, 2012) ~~as well as~~and by an isolated upper molar of uncertain provenance from the same area (van der Made and Ribot, 1999; Alba, 2012; Alba et al., 2013). ~~Hopefully,~~F ~~f~~uture fieldwork in these and other sites ~~will~~ should help to determine the taxonomic identity of earliest Vallesian hominoids from the Vallès-Penedès Basin ~~as well as~~and to clarify whether their rare co-occurrence with pliopithecoids at Castell de Barberà~~CB~~ and other localities was related to ~~exceptionally~~ particularly humid and/or densely forested environmental conditions as compared to most other sites from the same basin.

## 5. Summary and conclusions

Here we report ~~the results of~~ new magnetostratigraphic ~~sampling~~resultss for the primate-bearing ~~site of~~ Castell de Barberà~~CB~~ site~~collected in 2014–2015~~, together with ~~the~~ a ~~recent find of~~ *Hippotherium* find collected in 2015 from a stratigraphic horizon (CB-D~~layer D~~) equivalent to the original main ~~classical~~ fossiliferous layer at Castell de Barberà. We interpret these data in ~~the~~ light of ~~the~~ previously published literature and our own review of the rodent assemblage from Castell de Barberà~~CB~~, with the aim of providing an unambiguous and more accurate datе~~ing~~ for the site.

Our paleomagnetic results, coupled with ~~the~~ in situ recovery of a *Hippotherium* humerus, ~~rule out~~make it unlikely the ~~the~~ correlation of any of the various sampled normal polarity magnetozones with the long normal polarity subchron C5n.2n (11.056–9.984 Ma) that is characteristic of the early Vallesian, and support instead ~~a~~ correlation of CB-~~layer~~ D with C5r.1n (11.188–11.146 Ma), where the Aragonian/Vallesian boundary is situated. ~~All in~~ Overall, our results unambiguously indicate an ~~earliest~~ early Vallesian age ~~of ~11.2 Ma~~ for Castell de Barberà~~CB~~, thereby settling ~~the~~ longstanding debate about the Aragonian vs. Vallesian age of this site. Our results further support an earliest Vallesian (~11.2 Ma) age for ~~Therefore,~~ Castell de Barberà, which~~CB~~ would be roughly coeval with the ~~site of CCN20~~Creu de Conill 20 site, ~~which represents~~where the first appearance datum of hipparionins in the Vallès-Penedès Basin has been recorded.

~~The~~ Aaccurate dating of the Castell de Barberà site~~CB~~ provided in this paper ~~will allow~~is important to ~~better~~ contextualize ~~at a basin scale~~ the faunal and paleoenvironmental changes that enabled ~~the~~ coexistence of pliopithecoids and hominoids at ~~some~~ particular sites in the Vallès-Penedès Basin during the late Miocene. It also provides useful hints ~~so as~~ to redirect future fieldwork efforts in the Vallès-Penedès Basin, with the aim to clarify the taxonomic identity and/or phylogenetic relationships of ~~the~~ catarrhine primates that lived there during the earliest Vallesian.

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## Figure captions

**Figure 1.** Fossil primates from Castell de Barberà: the pliopithecoid *Barberapithecus huerzeleri* (A–L) and the large-bodied hominoid (M–O). A–K) IPS1724 (holotype), selected associated teeth from a single female individual, including the right $I^1$ (A), the left $C^1$ (B), and the left $C_1$ (C), in lingual (left) and labial (right) views, as well as the right $M^1$ (D), the right $M^2$ (E), the right $M^3$ (F), the right $P_3$ (G), the left $P_4$ (H), the left $M_1$ (I), the right $M_2$ (J), and the right $M_3$ (K), in occlusal views. L) IPS1823, male right $C^1$ in lingual (left) and labial (right) views. M) IPS4335, partial distal pollical phalanx, in palmar (left) and dorsal (right) views. N) IPS4333, right proximal pollical phalanx, from left to right in palmar, radial, ulnar, and distal views. O) IPS4334, distal fragment of right humeral diaphysis assigned to cf. *Dryopithecus fontani* by Alba et

al. (2012), from left to right in anterior, medial, posterior, and lateral views. Scale bars equal 1 cm, except for O (5 cm). Images are reproduced from previous papers by the authors: L) Alba and Moyà-Solà (2012: Fig. 2); M–N) Almécija et al. (2012: Fig. 1); O) Alba et al. (2011: Fig. 1).

**Figure 2.** A) Aerial photograph ~~showing the location~~ of the ~~classical~~ site of Castell de Barberà (CB), as well as that of the bottom of sections sampled~~s~~ for magnetostratigraphy in this study. Modified from base orthophotos downloaded from VISSIR v3.26 (ICGC, 2018: sheets 288-119 and 288-120, scale 1:5000), ©Institut Cartogràfic i Geològic de Catalunya, with permission ~~allowed by~~from licence Creative Commons (CC) – Attribution 4.0 International (CC BY 4.0; see http://www.icgc.cat/Ajuda/Avis-legal for ~~the~~ reuse policies allowed for ICGC web content~~s~~). B) Detail of Castell de Barberà~~CB~~ (Section 2) during the excavation of CB-~~layer~~ D (equivalent to the original main ~~classical~~ fossiliferous ~~level~~layer) in June 2015.

**Figure 3.** Simplified geological map of the Vallès-Penedès Basin. The location of Castell de Barberà is denoted by a black star. ~~The~~ T~~t~~op left inset: ~~shows the situation~~location of the Vallès-Penedès Basin within the Iberian Peninsula. Modified from Casanovas-Vilar et al. (2016a: Fig. 1).

**Figure 4.** Examples of NRM stepwise thermal demagnetization of samples of the Castell de Barberà composite section. Stratigraphic location of samples (uppercase letters) is indicated in Figure 5. Diagrams represent orthogonal projection of vector endpoint demagnetization data; black and white dots represent the projection on the

horizontal and vertical planes, respectively. Red lines represent the least-square fit defining the paleomagnetic direction. Q1 and Q2 indicates ranked quality (see SOM Table S1).

~~**Figure 4.** Right distal humeral fragment of *Hippotherium* sp. IPS87652 from Castell de Barberà (layer D, equivalent to the classical fossiliferous level) recovered in 2015 (A), as compared to those of *H. catalaunicum* IPS11117 from Can Llobateres (B) and IPS32449 from Polinyà (C, reversed). All specimens are depicted in anterior (left) and posterior (right) views.~~

**Figure 5.** Magnetostratigrapic results for the two sampled sections at Castell de Barberà ~~(CB)~~: A) S~~s~~ection 1 ~~(CB s.l.)~~; B) S~~s~~ection 2, where the site of Castell de Barberà ~~(CB s.s.)~~is located. Sideways triangles denote the stratigraphic position of paleomagnetic samples. Red letters and triangles indicate the location of samples from Figure 4. Black circles indicate directions of higher quality (Q1 and Q2), while white circles indicate directions of low quality (Q3)—see SOM Table S1. Abbreviations: c = conglomerates; l = lutites; s = sandstones; VGP = v~~V~~irtual g~~G~~eomagnetic p~~P~~ole.

**Figure 6.** Composite local magnetostratigraphic section for~~of~~ Castell de Barberà ~~(CB)~~ and its preferred correlation with the ~~Global~~ geom~~M~~agnetic p~~P~~olarity t~~T~~ime s~~S~~cale (GPTS; Ogg, 2012), as well as European land mammal ages (ELMA), MN (Mammal Neogene) units, and local biozones of the Vallès-Penedès Basin (after Casanovas-Vilar et al., 2016b). See Figure 5 for ~~the~~ detailed magnetostratigraphic results of the two sampled sections upon which this composite magnetostratigraphic section is based. Abbreviations: ~~CB1 = CB s.l. (section 1); CB2 = CB s.s. (section 2);~~ N =

normal polarity magnetozones; R = reversed polarity magnetozones. The arrow next to N2 denotes the stratigraphic position of the main ~~classical~~ fossiliferous ~~level~~ layer of Castell de Barberà (CB-D). Half-width polarity intervals in the GPTS represent short geomagnetic excursions after Evans et al. (2007). Short horizontal lines to the left of the polarity column represent 'tinny wiggles' from the sea floor magnetic anomaly stacks (Cande and Kent 1992), later interpreted as true geomagnetic polarity reversals (Roberts and Lewin-Harris, 2000).

**Figure 7.** Right distal humeral fragment of *Hippotherium* sp. IPS87652 from Castell de Barberà CB-D (equivalent to the main fossiliferous layer) recovered in 2015 (A), compared to those of *Hippotherium catalaunicum* IPS11117 from Can Llobateres (B) and IPS32449 from Polinyà (C, reversed). All specimens are depicted in anterior (left) and posterior (right) views.

# Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian~~: End of the controversy~~

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Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian

**Keywords:** Hominoidea; Pliopithecoidea; *Hippotherium*; Late Miocene; Magnetostratigraphy; Paleomagnetism.

**Abstract**

Castell de Barberà, located in the Vallès-Penedès Basin (NE Iberian Peninsula), is one of the few European sites where pliopithecoids (*Barberapithecus*) and hominoids (cf. *Dryopithecus*) co-occur. The dating of this Miocene site has proven controversial. A latest Aragonian (MN7+8, ca. 11.88–11.18 Ma) age was long accepted by most authors, despite subsequent reports of hipparionin remains that signaled a Vallesian age. On the latter basis, Castell de Barberà was recently correlated to the early Vallesian (MN9, ca. 11.18–10.3 Ma) on tentative grounds. Uncertainties about the provenance of the *Hippotherium* material and the lack of magnetostratigraphic data precluded more accurate dating. After decades of inactivity, fieldwork was resumed in 2014–2015 at Castell de Barberà, including the original layer (CB-D) that in the past delivered most of the fossils. Here we report magnetostratigraphic results for the original outcrop and another nearby section. Our results indicate that CB-D is located in a normal polarity magnetozone at about midheight of a short (~20 m-thick) stratigraphic section. The composite magnetostratigraphic section (~50 m) has as many as four to six magnetozones. These multiple reversals, coupled with the in situ recovery of a *Hippotherium* humerus from CB-D in 2015, make it very unlikely the correlation of any of the sampled normal polarity magnetozones with the long normal polarity subchron C5n.2n (11.056–9.984 Ma), which is characteristic of the early

Vallesian. Our results support instead a correlation of CB-D with C5r.1n (11.188–11.146 Ma), where the Aragonian/Vallesian boundary is situated, and therefore indicate an earliest Vallesian age of ~11.2 Ma for Castell de Barberà. Our results settle the longstanding debate about the Aragonian vs. Vallesian age of this site, which appears roughly coeval with the Creu de Conill 20 locality (11.18 Ma), where hipparionins are first recorded in the Vallès-Penedès Basin.

## 1. Introduction

### *1.1. Primates from Castell de Barberà*

The Miocene primate-bearing site of Castell de Barberà is situated along the left bank of the Ripoll River, near the old farmhouse of Ca n'Altimira, in the municipality of Barberà del Vallès (Catalonia, Spain). The site was named after a former medieval castle (11$^{th}$ century) that was subsequently reconstructed as a country house. According to museum labels, the site was mostly excavated from 1965 to 1981 by personnel from the former Instituto Provincial de Paleontología in Sabadell, currently the Institut Català de Paleontologia Miquel Crusafont (ICP), although the site was already mentioned in the catalog published by Crusafont and Truyols (1954). Crusafont Pairó and Hürzeler (1969) first reported the find of primate remains, and Crusafont-Pairó and Golpe (1972) later provided a summary account of the site, noting that methodical excavations had been carried out there. Although publications based on the previously collected material from Castell de Barberà have continued until recently, the site was not excavated for many years, until it was reopened in 2014 and 2015 under the direction of author#6 and author#7.

Among the Miocene primate-bearing sites of Europe, Castell de Barberà is renowned for being one of the few in which pliopithecoids and hominoids co-occur

(Moyà-Solà et al., 1990; Andrews et al., 1996; Alba, 2012; Sukselainen et al., 2015). It is unknown whether the hominoid remains come from the same layer as the pliopithecoid remains, which are attributed to the main fossiliferous layer that also yielded most of the fossils from the site (Alba and Moyà-Solà, 2012). However, the shortness of the stratigraphic section, coupled with the lack of obvious hiatuses, implies that all of the fossils from the site are roughly coeval.

Hominoids were first reported from Castell de Barberà by Crusafont Pairó and Hürzeler (1969), based on a purportedly female right upper canine (IPS1823 [IPS26 in old terminology]; Fig. 1L) that was subequently attributed (either implicitly or explicitly) to *Hispanopithecus laietanus* (sometimes included in *Dryopithecus*; Crusafont-Pairó and Casanovas Cladellas, 1973; Golpe-Posse, 1974; Golpe Posse, 1982, 1993; Harrison, 1991). Even though other authors later assigned this specimen to a male pliopithecoid (Begun, 2002a; Alba et al., 2011; Almécija et al., 2011, 2012; Alba and Moyà-Solà, 2012), hominoids are also recorded at Castell de Barberà by several postcranial remains. These were found among the museum collections in the late 1980s, as reported preliminarily by Moyà-Solà et al. (1990), and subsequently described in detail. The hominoid specimens consist of: a distal humeral diaphysis (IPS4334; Fig. 1O; Alba et al., 2011; Almécija et al., 2011), a proximal pollical phalanx (IPS4333; Fig. 1N; Moyà-Solà et al., 2005; Almécija et al., 2012), and a distal pollical phalanx (IPS4335; Fig. 1M; Almécija et al., 2012). Based on the large body mass inferred from the humeral shaft fragment, the hominoid from Castell de Barberà was tentatively referred to cf. *Dryopithecus fontani* (Alba et al., 2011; Almécija et al., 2011; Alba, 2012; Marigó et al., 2014), although such a tentative attribution cannot be further substantiated due to the lack of craniodental specimens (Almécija et al., 2012).

The pliopithecoid from Castell de Barberà, in turn, was first reported by Crusafont-Pairó (1975), based on several upper and lower teeth of a single individual (Fig. 1A–K) that was initially referred to *Pliopithecus* sp. Afterward, the lower dentition was described by Crusafont-Pairó and Golpe-Posse (1981a, 1982a), who similarly assigned the material to *Pliopithecus* sp., albeit noting similarities with *Pliopithecus lockeri* (currently in *Plesiopliopithecus*, i.e., a crouzeliid; Begun, 2002a; Alba and Berning, 2013). Some later authors advocated crouzeliid affinities for the Castell de Barberà pliopithecoid (Ginsburg, 1986), but most considered it to be a pliopithecid (Andrews et al., 1996; Begun, 2002a; Harrison et al., 2002). Some authors even attributed the material (although usually tentatively) to *Pliopithecus antiquus* (Moyà-Solà et al., 1990; Andrews et al., 1996; Harrison et al., 2002), whereas others considered it to represent a new (unnamed) species (Ginsburg, 1986; Begun, 2002a; Alba et al., 2010). Finally, a new genus and species, *Barberapithecus huerzeleri*, was described by Alba and Moyà-Solà (2012) to accommodate the currently available dental remains, which belong to three different individuals: the holotype (IPS1724; Fig. 1A–K), including 15 upper and lower teeth from a single individual (see also Urciuoli et al., 2018); the paratype (IPS34548), consisting of a $P_3$ from another individual; and IPS1823, the aforementioned male upper canine (Fig. 1L), which was included in the hypodigm but not designated as a paratype. Finally, Moyà-Solà et al. (2013) preliminarily reported a proximal fragment of right radius (IPS66267) assigned to *Barberapithecus*, found by Lars van den Hoek Ostende while revising the collections, although this specimen has yet to be described in detail.

During the Miocene, hominoids and pliopithecoids did not co-occur at many sites, which constitutes an apparent, although poorly-understood, pattern that has received attention in recent publications (Sukselainen et al., 2015; Alba et al., 2017, and references therein). Both groups are represented in late Aragonian and Vallesian sites of the Vallès-Penedès Basin (see subsection 1.2. below for further explanation on these terms), although they seldom come from the same locality (exact stratigraphic horizon), even when their ranges are known to overlap as in Abocador de Can Mata (Alba et al., 2017). This fact might be due to a sampling artifact related to the rarity of these primates (Andrews et al., 1996), or it might be related to different ecological preferences between these groups (e.g., Sukselainen et al., 2015). As one of the few sites recording both groups and amenable to paleoecological analyses based on the accompanying fauna, Castell de Barberà has the potential to shed light on the particular conditions that enabled the infrequent coexistence of hominoids and pliopithecoids throughout the European Miocene.

### *1.2. Vallesian and Aragonian European land mammal ages*

The contribution of Castell de Barberà to a broader understanding of primate evolution during the European Miocene in general, and the succession of primate taxa at the Vallès-Penedès Basin in particular, has been hampered by a longstanding controversy about the age of this site—whether it correlates to the Aragonian or with the Vallesian European land mammal ages (ELMAs). Some clarification is required with regard to the concept of ELMAs (for a historical review, see Lindsay and Tedford, 1990 and Van Dam, 2003), with particular emphasis on the use of 'Aragonian' instead of Orleanian + Astaracian, despite the latter are more widely used outside Spain. The use of ELMAs as geochronological units has been criticized (e.g., Steininger, 1999) on the grounds that they are regional and that, with few exceptions, they do not correspond to properly defined chronostratigraphic units (stages). 'Mammal ages' are generally conceptualized as "biochronologic units" (e.g., Woodburne, 2004a: xiv; see also Hilgen et al., 2012) of regional applicability due to divergent paleobiogeographic histories among regions (Lindsay and Tedford, 1990). However, an initial definition of land mammal ages as biochronologic units (i.e., biozones) is not mutually exclusive with their subsequent formal definition (based on bio- and magnetostratigraphic data) as chronostratigraphic units (i.e., stages based on bodies of rock formed during a given time interval; e.g., Garcés, 1995; Woodburne, 2004), which automatically implies the definition of their corresponding geochronologic units (ages).

The definition of regional chronostratigraphic units is not at odds with the International Stratigraphic Guide, because "It is better to refer strata to local or regional units with accuracy and precision rather than to strain beyond the current limits of time correlation in assigning these strata to units of a global scale" (Murphy and Salvador, 1999: 267). Even if not directly correlated with marine stages, regional continental units can be dated based on radiometric and/or paleomagnetic methods (e.g., Krijgsman et al., 1994; Garcés et al., 1996). Steininger (1999) conversely advocated abandoning a chronostratigraphic/geochronologic concept of ELMAs altogether and proposed to replace them by entirely biostratigraphic units ('European land mammal mega-zones') based on MN (Mammal Neogene) biozones (Mein, 1975). This proposal is not exempt of problems given that MN zones were defined as informal biochronologic units (Mein, 1975) and that their utility at a continental-wide scale is restricted due to the significant diachrony of most mammal biochronologic events (van der Meulen et al., 2011, 2012). This has led some authors to contend that a formal European biozonation is not possible (van der Meulen et al., 2012), which would imply that the regional nature of formally defined ELMAs such as the

Aragonian (see review in van der Meulen et al., 2012) would rather be an advantage with regard to providing accurate correlations.

The lack of formal (biostratigraphic and chronostratigraphic) definition of widely used biochronological units such as Orleanian and Astaracian is a problem that does not apply to the roughly time-equivalent Aragonian, since like the younger Vallesian (which enjoys a wider geographic applicability) it has been formally defined on the basis of a specific stratotype. Crusafont Pairó (1950, 1951, 1953, 1995; see also Crusafont Pairó and Truyols Santonja, 1954, 1955) first used the term Vallesian in a largely biochronological sense to designate the Vallès-Penedès deposits with *Hipparion* (currently *Hippotherium*) that, based on the fauna, appeared intermediate in age between the sites of La Grive in France (i.e., the Aragonian) and Pikermi in Greece (i.e., the Turolian). The Vallesian was finally more formally defined in reference to Vallès-Penedès mammal successions by Crusafont Pairó and Truyols Santonja (1960) based on the entry of *Hippotherium* as its main defining criterion. The Vallesian was rapidly accepted throughout Eurasia as a simple solution for the complex stratigraphic terminology in use, although it was not until decades later that it was formally defined as a 'mammal stage' based on a specific stratotype from the type area (the Vallès-Penedès Basin) within an accurate bio- and magnetostratigraphic framework (Garcés, 1995; Garcés et al., 1996; Agustí et al., 1997). Following the proposal of MN zones by Mein (1975), MN9 and MN10 had already been equated with the early and late Vallesian, respectively, in turn subdivided into multiple local biozones based on rodents (Agustí, 1981, 1982; Agustí and Moyà-Solà, 1991; Agustí et al., 1997; Casanovas-Vilar et al., 2011a, 2016b).

The Aragonian was in turn originally conceptualized (Falhbusch, 1976) as a chronostratigraphic unit defined by the presence of the equid *Anchitherium* and the lack of the more derived equid *Hipparion* (currently *Hippotherium*), and subdivided into two subunits, the Orleanian and the Astaracian. Soon thereafter, the Aragonian was defined by Daams et al. (1977) as a new stage for continental middle Miocene deposits preceding the Vallesian, with its stratotype located within the Calatayud-Montalbán Basin in Spain (see also Daams et al., 1999). However, Daams et al. (1977) refrained from dividing the Aragonian into Orleanian and Astaracian because the latter had yet to be formally defined, ultimately leading to a tripartite subdivision (Daams and Freudenthal, 1981; Daams and Freudenthal, 1990). Moreover, the original criterion used to define the base of the Aragonian (the dispersal of *Anchitherium*) was soon questioned (Daams and Freudenthal, 1981) and eventually abandoned following the definition of the Ramblian stage (Daams et al., 1987; see also Daams and Freudenthal, 1990). Further stratigraphic refinements of the Aragonian were later provided by Daams et al. (1987, 1999) and van der Meulen et al. (2012), who further distinguished multiple Aragonian local biozones based on rodents. Based on these works, currently the Aragonian may be considered a regional mammal-based chronostratigraphic unit (stage), whose scope is limited to the continental record from Spain (see recent reviews in van der Meulen et al., 2012 and García-Paredes et al., 2016). Given the scope of this paper and the detailed local zonation of the Aragonian available for the Vallès-Penedès Basin (Casanovas-Vilar et al., 2016b), we refrain from using the alternative and more loosely-defined term 'Astaracian'.

Based on high-resolution magnetostratigraphic correlation to the geomagnetic polarity time scale (GPTS), according to Van der Meulen et al. (2012) the early Aragonian (ca. 17.2–15.9 Ma) corresponds to the late Burdigalian (early Miocene, MN4), while the middle Aragonian (ca. 15.9–13.8 Ma) comprises most of the

Langhian (early to middle Miocene, MN5), and the late Aragonian (ca. 13.8–11.2 Ma, roughly equivalent to the 'Astaracian') covers the latest Langhian, the Serravallian, and the earliest Tortonian (middle to late Miocene, MN6 to MN7+8). The Vallesian, in turn, entirely corresponds to the Tortonian (late Miocene), being subdivided into early Vallesian (11.2–10.0 Ma, MN9) and late Vallesian (10.0–8.9 Ma, MN10; e.g., Hilgen et al., 2012; Casanovas-Vilar et al., 2016b).

*1.3. The controversial age of Castell de Barberà*

Originally, Crusafont and Truyols (1954), Crusafont-Pairó and Hürzeler (1969) and Crusafont-Pairó and Golpe (1972) advocated for a pre-Vallesian age for Castell de Barberà because no hipparionin remains were originally found. Crusafont-Pairó and Golpe (1972), Crusafont-Pairó (1972), and Golpe-Posse (1974) remarked that the fauna appeared somewhat intermediate between those of the late Aragonian (MN7+8) and those of the early Vallesian (MN9) localities of the Vallès-Penedès Basin (e.g., Trinxera del Ferrocarril in Sant Quirze vs. Can Llobateres, respectively). However, given the lack of hipparionins and the presence of giraffids, the above-mentioned authors correlated the site with the latest Aragonian. For many years, such a correlation was further supported by Crusafont and coworkers (Crusafont Pairó and Golpe Posse, 1972a; Golpe-Posse, 1972, 1974, 1975, 1977, 1978; Crusafont-Pairó and Golpe Posse, 1972b, 1974, 1981a,b, 1982a,b; Petter, 1976; Santafé Llopis, 1978; Santafé i Llopis, 1978a,b), even in the face of a surface-collected fragmentary fossil of *Hippotherium* already reported by Crusafont-Pairó and Golpe-Posse (1974). According to Crusafont-Pairó and Golpe-Posse (1974), the *Hippotherium* specimen was somewhat rounded and probably eroded from the uppermost fossiliferous layer of the Castell de Barberà section, whereas most of the fossil assemblage (lacking

*Hippotherium*) came from the main fossiliferous layer (situated at about the midheight of the ~20 m-thick outcrop section). Crusafont-Pairó and Golpe-Posse (1974) considered that the main fossiliferous layer was undoubtedly pre-Vallesian and only contemplated two possible explanations for the presence of *Hippotherium* at the site: either *Hippotherium* arrived in the Vallès-Penedès Basin during the latest Aragonian (irrespective of whether the aforementioned fragment came from the main or the upper fossiliferous layers); or the Aragonian/Vallesian boundary was located above the main fossiliferous level along the upper portion of the Castell de Barberà section (assuming the *Hippotherium* fragment came from the upper layer).

Needless to say, the first possibility discussed by Crusafont-Pairó and Golpe-Posse (1974)—namely, a pre-Vallesian appearance of *Hippotherium*—is an ad hoc explanation that does not hold upon closer scrutiny because it is at odds with the original definition of the Vallesian proposed by Crusafont on the basis of the first appearance datum of *Hippotherium* (formerly *Hipparion*; Crusafont Pairó, 1950, 1951, 1953; Crusafont Pairó and Truyols Santonja, 1960). The second explanation, in contrast, remained a reasonable hypothesis that would be falsified by *Hippotherium* remains from the main Castell de Barberà fossiliferous layer. There is a third possible explanation, namely that Castell de Barberà could be Vallesian in age, even if *Hippotherium* was scarce or absent.

For many years and up to the present, most subsequent authors favored a correlation of Castell de Barberà with the late Aragonian (Moyà-Solà, 1983; Agustí et al., 1985, 2001, 2013; Moyà-Solà et al., 1990; Begun, 2002a; van den Hoek Ostende and Furió, 2005; Alba et al., 2006, 2010, 2011; Casanovas i Vilar, 2007; Casanovas-Vilar et al., 2008, 2011a; Robles et al., 2010; Almécija et al., 2011; Sukselainen et al., 2015; Agustí, 2018). The various alternate possibilities discussed above were generally not discussed further, or were dismissed on the grounds that the specimen was purportedly washed down from upper layers of the outcrop section (e.g., Santafé Llopis, 1978; van den Hoek Ostende and Furió, 2005; Casanovas i Vilar, 2007; Alba et al., 2011). However, it should be taken into account that the uppermost layers are close (<10 m) to the main fossiliferous layer of Castell de Barberà (Casanovas-Vilar et al., 2016b). The relatively short stratigraphic distance (110 m, according to Crusafont Pairó and Truyols Santonja, 1951) between Castell de Barberà and Can Llobateres 1 (with an interpolated age of 9.76 Ma; Casanovas-Vilar et al., 2016b) also adds difficulty to the considerable age difference estimated between the two localities (Alba and Moyà-Solà, 2012; Casanovas-Vilar et al., 2014)—which would require the existence of major faults (e.g., Agustí et al., 1985) that have yet to be documented. Some authors remained open to (Aguilar et al., 1979; Ginsburg, 1986), or even supported (Gibert, 1975; de Bruijn et al., 1992; Andrews et al., 1996), an alternate correlation of Castell de Barberà with MN9. However, it was not until publication of a *Hippotherium* lower molar discovered among the museum collections of Castell de Barberà (Rotgers and Alba, 2011) that most authors started to favor a Vallesian age for the site (Casanovas-Vilar et al., 2011b, 2014, 2016a,b; Alba, 2012; Alba and Moyà-Solà, 2012; Almécija et al., 2012; Robles et al., 2013a,b; Furió et al., 2015; Villa et al., 2017). Casanovas-Vilar et al. (2014) even estimated an age of 10.55 Ma for the site based of the stratigraphic distance between Castell de Barberà and Can Llobateres reported by Crusafont Pairó and Truyols Santonja (1951). Casanovas-Vilar et al. (2016a,b) then correlated Castell de Barberà to the *Hippotherium – Cricetulodon hartenbergeri* interval subzone (11.88–10.3 Ma) of the Vallès-Penedès Basin without further specifying its age. However, these authors considered that such a correlation, which has yet to gain universal acceptance (e.g., Agustí et al., 2013; Sukselainen et al., 2015; Agustí, 2018), must be considered tentative—given uncertainties about the exact provenance of the *Hippotherium* remains from Castell de Barberà, which would still allow a latest Aragonian age for the main fossiliferous layer.

With the aim of performing magnetostratigraphic analyses to more conclusively settle the age of the Castell de Barberà sequence and hopefully lead to the find of additional fossils, a team from the ICP led by author7 and author6 planned to reopen the Castell de Barberà site in 2014. Finding the exact location of the site was hampered by the vagueness of published indications (Crusafont-Pairó and Golpe, 1972; Golpe Posse, 1974), coupled with decades of vegetation growth and recent anthropic modifications (to enlarge the riverbank's trackway). Two paleontological campaigns were performed there in 2014 and 2015 with the aid of an excavator machine (Fig. 2). Excavations in 2014 focused on a section (Section 1) situated less than 300 m from the original outcrop (Section 2), which was excavated in 2015. The exact geographic and stratigraphic situation of the original main fossiliferous layer in Section 2 was located thanks to collaboration of the late Josep V. Santafé, who had repeatedly excavated at the site during the 1970s with Crusafont, and indicated the exact location while visiting the site during the 2015 season. Although our work confirms that the bone accumulation of the main Castell de Barberà fossiliferous layer is exhausted, we recovered additional fossil remains from the same layer and other layers, and took paleomagnetic samples from the two excavated sections. In this paper, we report the magnetostratigraphic data, and, with the aid of biostratigraphic considerations, provide a more accurate dating of Castell de Barberà and discuss its implications for Miocene hominoid and pliopithecoid evolution (for a preliminary report of these data, see Alba et al., 2018a,b).

## 2. Materials and methods

*2.1. Location and stratigraphy of Castell de Barberà*

From a geological viewpoint (Fig. 3), Castell de Barberà is located on the distal facies of the Castellar del Vallès alluvial fan system, which belong to the middle to late Miocene upper continental complexes of the Vallès-Penedès Basin in NE Iberian Peninsula (Agustí et al., 1985; Garcés, 1995; de Gibert and Casanovas-Vilar, 2011). These outcrop sediments mostly consist of mudstones (especially siltsones and some finer claystones) with intercalated coarse to fine sandstones (Santafé Llopis, 1978). The repeated alternation of these lithologies along the stratigraphic series may be interpreted as energy cycles—from higher energy at the base of each cycle, where sandstones are more abundant, to lower energy toward the top, where fine siltstones and claystones were deposited.

Most of the specimens from the collections of Castell de Barberà (mostly amassed between 1965–1981) lack associated information. When preserved, some old field labels refer to ‘layer 1’, and more sporadically to a so-called ‘higher layer’. Despite this, it is possible to confidently assert that most of the material came from a single layer (Santafé Llopis, 1978), which according to J.V. Santafé (pers. comm. to author6 and author7) was stratigraphically equivalent to layer CB-D excavated in 2015 (Fig. 2B). Santafé Llopis (1978) provided coordinates for the site (31N 428291 E – 4597272 N), indicating that it would be situated close to Ca n’Altimira. However, the published coordinates are at odds with the description of the site location, and that confirmed by Santafé in the field is situated more than 400 m southward (31N 428314 E – 4596862 N; Fig. 2A)[1].

Two magnetostratigraphic sections, located along the left bank of the Ripoll River and exposed with the aid of digging machinery, were sampled for this study (Figs. 2A and 4): Section 1 was excavated in 2014 close to Ca n'Altimira (bottom: 31 N 428232 E – 4597224 N), and Section 2 was excavated in 2015 at the original outcrop (bottom: 31N 428316 E – 4596888 N). The horizontal distance between the two points is 346 m. Strata dip gently toward the east, and altitude differences between the two points are negligible (both are situated ~95 m above sea level). Both sections (Supplementary Online Material [SOM] S1 and Fig. S1) were correlated on lithostratigraphic grounds based on the assumption that there is no major fault located between the two sections. In particular, considering a bedding orientation of 002/10E (strike/dip), measured in outcropping layers in both sections, the bottom of magnetostratigraphic Section 1 would be stratigraphically situated 16.6 m below the bottom of Section 2. Given that Section 1 has a thickness of almost 50 m and Section 2 of about 20 m, these results imply that, unless there is a fault between the two sections, they must overlap to a large extent (SOM Fig. S1). Such correlation methodology is far from ideal, not only because it has to assume the lack of major faulting, but also because it does not take into account lateral changes in lithology and local accumulation rates. However, such an approach was unavoidable given the

[1] Geographic coordinates are given in the Universal Transverse Mercator – European Terrestrial Reference System 1989 (UTM ETRS89). They were verified using topographic maps and orthophotos from the web application VISSIR v3.26 of the Institut Cartogràfic i Geològic de Catalunya (ICGC, 2018).

dense vegetation cover between the two sections and the impossibility to deforest the whole riverbank in between.

*2.2. Paleomagnetism and biostratigraphy*

A total of 25 samples from 14 magnetostratigraphic sites were collected along the ~50 m-thick Section 1, although most samples are concentrated in the lower portion (~20 m in thickness) of the section. Also, 22 samples from 11 sites were collected along the 20 m-thick Section 2. No further samples were taken due to the presence of unsuitable coarse-grained lithologies and the inaccessibility of other outcrops.

All samples were subjected to stepwise thermal demagnetization (Fig. 4) to isolate the paleomagnetic components contributing to the natural remanent magnetization (NRM). Temperature increments of 50 to 30 °C were applied up to complete demagnetization of the samples or to temperatures at which acquisition of spurious magnetization caused unstable behavior. Maximum unblocking temperatures close to 600 °C indicate that the magnetic remanence is carried by iron oxides. In earlier studies of these sedimentary sequences (Garcés et al., 1996), detrital magnetite has been reported as the main remanence carrier, together with pigmentary and detrital hematite.

Stepwise demagnetization reveals the presence of a stable magnetic component at temperatures above 250 °C, which demagnetizes at temperatures up to about 600 °C. A characteristic magnetization direction was calculated by means of least-squares analysis for each sample (Kirschvink, 1980). Complete demagnetization could rarely be achieved, as thermal treatment often led to the acquisition of a spurious remanence above 400 °C—likely related to chemical alteration of Fe-bearing minerals and growth of new magnetite upon heating. Fortunately, the direction of the magnetic remanence often remained stable between 250 and 400 °C, and a paleomagnetic direction could be calculated from this temperature range. Anchoring the solutions to the origin was needed in most of cases as a clean progressive decay of the remanence could not often be observed (Fig. 4). A total of 47 paleomagnetic directions were obtained (SOM Table S1) and were ranked into three quality categories. Q1 directions (9 samples) were obtained from samples showing a gradual and nearly complete decay towards the origin. Q2 directions (32 samples) were obtained from samples that underwent unstable behavior at temperatures typically above 400 °C. Q3 directions (6 samples) were obtained from samples that underwent unstable at temperatures lower than 400 °C and did not show a clear decay of its remanence upon heating, and were not considered for polarity interpretation. A polarity interpretation of the paleomagnetic directions was done by calculating the latitude of the virtual geomagnetic pole (VGP) for each sample. Positive and negative VGP latitudes correspond to normal and reversed polarity, respectively (Fig. 4).

To aid interpretation of the paleomagnetic data, we provide an updated faunal list of the rodent assemblage from Castell de Barberà, which includes the material recovered in 2014–2015. Given its biostratigraphic significance, we further review the few hipparionin remains from the site, including a distal humeral fragment (IPS87652) that was found in 2015. All the fossils are housed at the ICP.

## 3. Results

### *3.1. Magnetostratigraphy*

Our paleomagnetic results (Fig. 5) indicate that at least four magnetozones are recorded in Section 1 (beginning with a reversed polarity one), whereas two magnetozones are recorded in Section 2 (beginning with a normal polarity magnetozone, in which CB-D is situated). The stratigraphic distance of ca. 17 m between the bases of the two sections would suggest that six magnetozones have been sampled (Fig. 6), with the first normal polarity magnetozone of Section 2 (i.e., that of the original main fossiliferous layer) being correlated with the second normal polarity magnetozone of Section 1 (N2), and with the reversed polarity magnetozone of Section 2 (R3) not having been sampled in Section 1. Given the close distance between the two sections, local accumulation rate differences are negligible. However, some uncertainties remain, because it is impossible to completely dismiss the presence of one or more small faults between the two sections, thus allowing for other (even if less likely) alternate correlations. Assuming that both sections completely overlap, it might be conceivable to correlate the first normal polarity magnetozone of Section 2 with the first normal polarity one of Section 1, which results in only four magnetozones. Other possible correlations, involving only partial overlap between the two sections, would imply up to five magnetozones, with the normal polarity magnetozone of Section 2 being older than all of Section 1 or, alternatively, with the normal polarity magnetozone of Section 2 being correlated with the uppermost portion of Section 1.

### *3.2. Rodent biostratigraphy*

Scanty reports of rodents in the intial faunal lists from Castell de Barberà (Crusafont-Pairó and Golpe, 1972; Crusafont-Pairó and Casanovas Cladellas, 1973; Crusafont-Pairó and Golpe-Posse, 1974; Golpe-Posse, 1974) were soon followed by a detailed study (Aguilar et al., 1979) that recognized four cricetids and five glirids. After multiple additions and refinements (Agustí, 1981; Agustí et al., 1985; Aldana Carrasco, 1992a,b,c; Casanovas i Vilar, 2007), the most recently published list is that of Casanovas-Vilar et al. (2016b), with up to 16 species. According to our own taxonomic revision of the material, the previously collected Castell de Barberà rodent assemblage, which is composed of 785 identifiable rodent remains, records up to 16 species, plus four additional ones recognized on the basis of the material recovered in 2015 (Table 1).

### *3.3. Presence of* Hippotherium

It is uncertain what specimen Crusafont-Pairó and Golpe-Posse (1974) originally identified as *Hipparion* (currently, *Hippotherium*) at Castell de Barberà. However, Rotgers and Alba (2011) reported and figured a *Hippotherium* $M_3$ (IPS57437) from the Castell de Barberà collections. The possibility of a misrecorded provenance is unlikely given that the specimen was clearly labeled. In our recent re-examination of the large mammal collections, we also found a $dP^2$ germ (IPS92389) attributable to this taxon. Crusafont-Pairó and Golpe-Posse (1974) did not figure or describe the specimen attributed by them to *Hippotherium*, but merely referred to it as a somewhat rounded fragment—which might apply to the above-mentioned deciduous premolar, although it is not possible to be certain. While the exact stratigraphic provenance of these remains is not recorded, even if they both came from the upper layer they would still be relevant for interpreting the magnetostratigraphic results, indicating a Vallesian age for at least the topmost portion of the section.

Moreover, we recovered from CB-D during the 2015 field season a distal humeral fragment (IPS87652) of an equid (Fig. 7A) that is virtually indistinguishable in both size and shape from Vallesian *Hippotherium* specimens from the same basin (Fig. 7B, C). The taxonomic attribution of IPS87652 to *Hippotherium* is complicated by the fact that both anchitheriine and hipparionin equids co-occur in some Iberian early

Vallesian localities and elsewhere in Europe (Salesa et al., 2004; Daxner-Höck and Bernor, 2009; Rotgers and Alba, 2011; Bernor et al., 2017). Although IPS87652 is fragmentary, the preserved portion of the distal diaphysis and epiphysis enable taxonomically meaningful morphological comparisons, which are provided below given the biostratigraphic relevance of *Hippotherium*.

In terms of size, IPS87652 fits well with *Hippotherium* (*primigenium*) humeri from elsewhere in Europe, as measured by the mediolateral width of the distal epiphysis (70.0 mm), which is well within the range of the Höwenegg (MN9, Germany) sample of *Hippotherium primigenium* ($\bar{X}$ = 70.5 mm, range = 65.3–74.1 mm, $n$ = 13; Bernor et al., 1997: Table 6.2). In contrast, the size of the specimen rules out an attribution to any *Anchitherium* species from the Iberian Peninsula (and elsewhere in Europe), which are smaller (Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011). On size grounds, IPS87652 would only be consistent with the much larger anchitheriine *Sinohippus sampelayoi* (formerly in *Anchitherium*), which is recorded at Nombrevilla 1 (MN9) in Spain (Salesa et al., 2004). Nonetheless, the latter species has not been recorded in the Vallès-Penedès Basin, where available anchitheriine remains from both the late Aragonian (Abocador de Can Mata) and early Vallesian (Can Poncic 1) indicate a much smaller size (Crusafont-Pairó and Golpe-Posse, 1974; Crusafont-Pairó, 1976; Sánchez et al., 1998; Rotgers et al., 2011; Rotgers and Alba, 2011). Furthermore, on qualitative morphological grounds IPS87652 also more closely resembles *Hippotherium* than anchitheriines. The most relevant feature is the larger trochlea relative to the smaller capitulum. In particular, IPS87652 resembles *Hippotherium* in the mediolaterally wide and cylindrical trochlea and proximodistally short capitulum, in contrast to the mediolaterally narrower and more globular trochlea and longer capitulum of anchitheriines (MacFadden, 2001). Therefore, the distal articular surface of IPS87652 is clearly *Hippotherium*-like and distinct from the more primitive pattern displayed by anchitheriines (SOM Fig. S2). Moreover, medial to the lateral epicondyle (between the lateral surface of the radial fossa and the lateral epicondylar crest), IPS87652 posseses a narrow but deep groove that marks the extensive origin attachment of the extensor digitorum communis muscle (Bernor et al., 1997). This feature is consistently present in the *Hippotherium* sample from Höwenegg (Bernor et al., 1997) but absent or weakly developed in anchitheriines (SOM Fig. S2). Overall, both size and shape support a confident assignment of IPS87652 to *Hippotherium*, in agreement with scarce dental material of this taxon previously reported from Castell de Barberà (Rotgers and Alba, 2011).

## 4. Discussion

### *4.1. Biochronology*

Among Miocene terrestrial assemblages, rodents are generally greatly significant for accurate dating of fossil sites, even when magnetostratigraphic data are available. This is because paleomagnetism only provides a binary signal, whose interpretation critically relies on independent constraints. In the Vallès-Penedès Basin, a revised scheme of local biozones and subzones largely based on rodents was recently provided by Casanovas-Vilar et al. (2016b). The only (but most remarkable) exception in this regard concerns the Aragonian/Vallesian boundary, which is defined by the first appearance datum of the equid *Hippotherium*. This is because the beginning of the Vallesian was not accompanied by important changes in the rodent faunas (Agustí et al., 1997, 2001). Therefore, according to Casanovas-Vilar et al. (2016b), the latest Aragonian corresponds to the *Democricetodon crusafonti* – *Hippotherium* interval subzone (MN7+8, 11.88–11.18 Ma), whereas the earliest

Vallesian corresponds to the *Hippotherium – Cricetulodon hartenbergeri* interval local subzone (MN9, 11.18–10.3 Ma)[2]. For Castell de Barberà, the most significant datum provided by rodents is the lack of *Cricetulodon*, which precludes correlation with the *Cricetulodon hartenbergeri* range subzone (MN9, 10.3–9.98 Ma) and indicates conclusively an age older than 10.3 Ma. Otherwise, however, the rodent assemblage is consistent with both a late Aragonian or early Vallesian age. In contrast, the presence of *Hippotherium* at Castell de Barberà (Fig. 7A) implies—by definition—a post-Aragonian age.

Given the restricted evidence provided by the rodent faunas at Castell de Barberà, Casanovas-Vilar et al. (2014, 2016a, b) favored a correlation of this site with the earliest Vallesian mostly based on the presence of hipparionins, even if they did so tentatively, given uncertainties about the provenance of scarce available material. Although the record of *Hippotherium* at Castell de Barberà was already reported by Crusafont-Pairó and Golpe-Posse (1974), most later authors dismissed its biochronological significance by arguing that the specimen came from a layer above the main fossiliferous layer. Our revision of the museum collections indicates that *Hippotherium* is recorded at Castell de Barberà by two dental specimens. Even if both teeth came from a stratigraphically higher layer, these remains would indicate, at least (given the thickness of the outcrop section), that the main fossiliferous layer would be situated less than 10 m below unambiguously Vallesian layers. Longstanding

[2] Interval zones are defined by two specified biohorizons (in these cases, corresponding to the lowest occurrences of the specified taxa), and termed with the name of the taxon defining the basal boundary preceding that of the taxon defining the top boundary (Murphy and Salvador, 1999).

discussion about the exact stratigraphic provenance of the material is now irrelevant after the find of the distal humeral fragment of *Hippotherium* reported in this paper, from a layer stratigraphically equivalent to the original main fossiliferous layer. This find settles this issue by indicating unambiguously that Castell de Barberà is Vallesian in age, even if a large portion of the rest of the fauna is still reminiscent of the late Aragonian.

The first appearance datum of *Hippotherium* in the Vallès-Penedès Basin is currently dated to 11.18 Ma, based on magnetostratigraphic correlation of the section in which Creu de Conill 20 (CCN20) is situated (Garcés et al., 1997; Agustí et al., 1997; Casanovas-Vilar et al., 2016a,b). The taxonomic identity of the earliest hipparionins from the Vallès-Penedès Basin is uncertain, partly due to the lack of diagnostic material and also because the alpha-taxonomy of *Hippotherium* is yet to be settled conclusively—particularly with regard to the earliest representatives of the genus (e.g., Bernor et al., 2017). Some authors have considered that the type species of the genus, *H. primigenium*, is a single polymorphic species with many regional variants (Pesquero and Arribas, 2002; Zouhri and Bensalmia, 2005). However, we follow Bernor et al. (1996) in recognizing that *H. primigenium* is best considered a species complex, which may be formally designated as *Hippotherium* (*primigenium*) spp.[3] The nominal species *Hippotherium catalaunicum*, erected by Pirlot (1956) based on material from els Hostalets de Pierola, is available for the Vallesian *Hippotherium* remains from the Vallès-Penedès Basin. This species has been considered a junior subjective synonym of *Hippotherium primigenium* by several authors (Forstén, 1968,

[3] The parentheses around the epithet denote a supraspecific species-group taxon, such as a species group or superspecies (see ICZN, 1999: Art. 6.2)

1978; Alberdi, 1972; Pesquero and Arribas, 2002; Zouhri and Bensalmia, 2005), but here we follow Bernor and colleagues (Bernor et al., 1996; Bernor and Armour-Chelu, 1999) in accepting a distinct species status for this taxon within the *Hippotherium primigenium* complex—i.e., *Hippotherium* (*primigenium*) *catalaunicum*. Nevertheless, we refrain from attributing the scanty Castell de Barberà specimens to this species because they do not allow to assess its purportedly derived distinguishing features from *Hippotherium primigenium* s.s. (namely, a very elongate and anteroposteriorly oriented preorbital fossa; Bernor et al., 1996).

Pending a more detailed study, caution in taxonomic assignment of the *Hippotherium* remains from Castell de Barberà is further advised by the plesiomorphic dental morphology of the earliest *Hippotherium* samples from elsewhere in Europe (see below). In the Vallès-Penedès Basin, the interpolated age of Creu de Conill 20 fits well with that of the earliest Vallesian hipparonins from Pannonian C (ca. 11.4–11.0 Ma) localities (Atzelsdorf and Gaiselberg) of the Vienna Basin, Austria (Woodburne, 2007, 2009; Bernor et al., 2017), which are as yet unassigned to species and appear more plesiomorphic than *H. primigenium* from the type locality (Eppelsheim) and other Central European localities. These earliest hipparionins from Europe most closely resemble *Cormohipparion* sp. from the earliest late Miocene (ca. 11.5 Ma) of North America (Woodburne, 2005, 2007), and suggest that *Hippotherium* is the descendant of a single dispersal event of *Cormohipparion* from North America into Eurasia sometime after 11.5 Ma (Woodburne, 2009; Bernor et al., 2017). According to Harzhauser (2009), Atzelsdorf would be ca. 11.2–11.1 Ma in age—i.e., roughly coeval to Creu de Conill 20—whereas elsewhere in the Iberian Peninsula *Hippotherium* dispersal is not documented until somewhat later (within C5n.2n, ca. 10.8–10.7 Ma) in the Calatayud-Daroca Basin (Garcés et al., 2003).

With regard to the biostratigraphic significance of the lack of *Hippotherium*, it should be considered that, as illustrated by some Vallès-Penedès sites, this taxon may be rare during the earliest Vallesian. This is best illustrated by the local section of Ecoparc de Can Mata, where *Hippotherium* has yet to be recorded despite being stratigraphically situated above the Aragonian/Vallesian transition—as indicated by litho-, magneto-, and rodent biostratigraphic data (Alba et al., 2012; Casanovas-Vilar et al., 2016b). Therefore, caution is required when inferring the age of other sites chronologically close to the Aragonian/Vallesian boundary because the absence of *Hippotherium* does not necessarily imply a pre-Vallesian age (e.g., Can Missert; see discussion in Robles et al., 2011; contra Agustí et al., 2005)—and is alternatively attributable to ecological conditions (e.g., unsuitable local habitat) and/or taphonomic factors (i.e., sampling bias). Equating the lack of *Hippotherium* with a late Aragonian age originally led to the misdating of Castell de Barberà, and this reasoning has been further perpetuated despite clear (even if scarce) evidence that *Hippotherium* was recorded at least somewhere within the short section where the site is located. When both rodents and *Hippotherium* are considered together, biostratigraphic data enable unambiguous correlation of Castell de Barberà with the *Hippotherium – Cricetulodon hartenbergeri* interval local subzone (11.18–10.3 Ma; Fig. 6), as previously supported by Casanovas-Vilar et al. (2016a, b) on tentative grounds.

*4.2. Magnetostratigraphy*

The magnetostratigraphic data reported in this paper enable more accurate dating of Castell de Barberà within the early Vallesian, even if the shortness of the sampled sections allows several possible interpretations. The most parsimonious interpretation, based exclusively on the stratigraphic distance between the two sections as computed from dip measurements, implies as much as six magnetozones. Other interpretations imply four to five magnetozones. Irrespective of the preferred interpretation, regarding correlation of the identified magnetozones with the GPTS (Ogg, 2012), two important factors should be considered. First, the main fossiliferous layer of Castell de Barberà is situated in a normal polarity magnetozone. Second, no matter what correlation between the two sections is preferred, there are at least four magnetozones within a short 50–80 m sequence. Taking into account an average sedimentation rate of ~20 cm/kyr, computed for both the Vallesian (Garcés et al., 1996) and the late Aragonian (Alba et al., 2017) of the Vallès-Penedès Basin, the sampled interval would not represent more than 400 kyr. The frequent alternation of normal and reversed polarity magnetozones in the composite sequence of Castell de Barberà indicates that the long normal subchron C5n.2n that is characteristic of the early Vallesian is not recorded in the sampled interval. Only the uppermost normal polarity magnetozone N3 could correlate with the base of C5n.2n. The magnetostratigraphic results rather suggest that most of the composite sequence correlates with the upper C5r, where multiple reversals are recorded over a short time interval (Ogg, 2012).

An alternate correlation of the reversed polarity magnetozones R2 and R3 with some cryptochrons or geomagnetic excursions within C5n.2n (Cande and Kent, 1992; Roberts and Lewin-Harris, 2000; Evans et al., 2007) is considered unlikely because of the short duration, possibly less than 10 kyr, of these events. While chances of recording such short geomagnetic features in fluvial sediments are typically low, to record as many reversed polarity directions as normal polarity directions within C5n.2n is considered implausible. The fact that all the reversed polarity magnetozones documented at Castell de Barberà are recorded by more than a single paleomagnetic sample strongly argues against any of them representing a short-lived excursion event within C5n.2n. The similar thickness of the documented normal and reversed polarity magnetozones at Castell de Barberà strongly argues against this possibility, and favor a correlation of most of the sequence with chron C5r.

In our preferred interpretation (Fig. 6), the lowermost normal polarity magnetozone of Section 1 would be correlated with subchron C5r.2r-1 (11.308–11.263 Ma), and the lowermost normal polarity magnetozone of Section 2 (i.e., the main fossiliferous layer), like the second normal polarity magnetozone of Section 1, with C5r.1n (11.188–11.146 Ma). According to this interpretation, the original outcrop of Castell de Barberà, including the main fossiliferous layer at about the middle of the sequence and its uppermost layers, would cover a time span approximately between 11.2 and 11.1 Ma. Such a correlation would be compatible with the composite sequence recording six magnetozones (with the uppermost portion of the composite sequence, recorded in Section 1, correlated to the lowermost part of subchron C5n.2n). This correlation would be also compatible with an alternate interpretation of the composite sequence recording only four magnetozones, with the lower normal polarity magnetozones of each section correlated to the same subchron, either C5r.2r-1 or C5r.1n. However, correlation with the former subchron is much more unlikely because it would imply a first appearance datum of *Hippotherium* about 100 kyr older than previously documented in the Vallès-Penedès Basin and elsewhere in Eurasia (Garcés et al., 1997; see also above). An older age for the bottom of Section 2 (normal polarity) relative to that of Section 1 (reversed polarity), implying five magnetozones, would also imply a correlation of the first normal polarity magnetozone of Section 2 with C5r.2r-1, which is similarly unlikely.

In summary, although there are several possible interpretations about the number and correlation of magnetozones recorded in the two sampled sections, the combined magnetostratigraphic and biostratigraphic data favor correlation of the main fossiliferous layer of Castell de Barberà with subchron C5r.1n. An alternative correlation with the long normal polarity chron C5n.2n, which is characteristic of the early Vallesian, is precluded by the presence of a reversed polarity magnetozone at the top of the main fossiliferous layer—unless such a reversed polarity magnetozone is interpreted to represent a cryptochron, which seems highly unlikely as discussed above. I turn, correlation with the older and short normal polarity subchron C5r.2r-1 is possible, but is not favored here because it would imply a first appearance datum of *Hippotherium* of ca. 100 kyr older than previously documented. According to our interpretation of the results, the main fossiliferous layer of Castell de Barberà would be roughly equivalent in age to Creu de Conill 20 (11.2 Ma), and both sites would represent the earliest Vallesian faunas of the Vallès-Penedès Basin, with the uppermost layers of the original Castell de Barberà outcrop, which also delivered some fossil remains, being correlated with C5r.1r and with an estimated age closer to 11.1 Ma. Only layers underlying the main fossiliferous layer might be latest Aragonian instead of earliest Vallesian, although they would be correlated with the same subchron and would have a similar estimated age to the nearest 0.1 Ma.

*4.3. Implications for primate evolution*

As one of the few European Miocene localities where pliopithecoids and hominoids are recorded, Castell de Barberà is a key site for better understanding why their co-occurrence is so rare. However, lack of accurate dating for Castell de Barberà represented a serious drawback for adequately contextualizing this phenomenon within the framework of faunal and paleoenvironmental changes in the Vallès-Penedès Basin. Sukselainen et al. (2015) concluded that pliopithecoids inhabited generally more 'humid' environments than hominoids, and further suggested that the few localities hosting a species from each group might have had even more 'humid' conditions than other primate-bearing European Miocene localities. This study relied on the hypsodonty of larger herbivorous mammals as a proxy for vegetation structure, which in turn has been used as a proxy for past humidity and precipitation (Sukselainen et al., 2015, and references therein), so that their conclusions are more adequately interpreted as indicating more closely forested conditions for primate-bearing localities (particularly those in which the two groups co-occur) as a result of higher humidity (moisture), precipitation (rainfall), or both. This interpretation is consistent with previous paleoecological analyses by Casanovas-Vilar et al. (2008), which found that Castell de Barberà would have been more 'humid' (i.e., higher moisture and/or precipitation) and displayed a more marked evergreen vegetation component than late Aragonian hominoid-bearing localities from the Vallès-Penedès Basin.

Particularly 'humid' conditions at Castell de Barberà are consistent with the high abundance of swimming castorids. They are represented by two species: the small *Euroxenomys minutus*—more than half of the rodent remains recovered using screen-washing techniques from Castell de Barberà belong to this taxon—and the much rarer *Chalicomys jaegeri*, which was the size of the extant beaver (Casanovas-Vilar and Agustí, 2007; Casanovas-Vilar et al., 2008, 2010). These taxa indicate the presence of permanent water bodies nearby, although not necessarily of humid and densely forested habitats. Nevertheless, in the framework of Vallès-Penedès regional setting it is consistent with the fact that Vallesian hominoids from this basin have been linked to forested humid habitats providing a year-round fruit supply (Marmi et al., 2012; Alba et al., 2018c)—such as that from Can Llobateres 1, which on the basis of plant remains has been reconstructed as a very humid marshy area with nearby dense wetland forests including some (sub)tropical elements (Marmi et al., 2012). The record of the anuran *Latonia* is also indicative of locally humid and warm conditions (Villa et al., 2017), and besides the presence of primates and beavers, a closed forested environment at Castell de Barberà is further supported by the presence of certain forest-dwelling taxa, such as arboreal dormice (*Bransatoglis*, *Glirudinus*, *Muscardinus*, *Myoglis*, *Paraglirulus*) and flying squirrels (*Miopetaurista* and probably *Albanensia*), which are more diverse and abundant at Castell de Barberà than in roughly contemporary sites (Casanovas-Vilar and Agustí, 2007; Casanovas-Vilar et al., 2008, 2010). Finally, certain cricetids (*Eumyarion*, *Anomalomys*) may have also preferred densely forested habitats because they tend to be more abundant in fossil faunas rich in glirids and flying squirrels (Casanovas-Vilar and Agustí, 2007).

The apparently more humid and densely forested paleoenvironmental conditions of Castell de Barberà as compared to late Aragonian localities from the same basin could be explained to some extent by differences in age. However, even if the earliest Vallesian is not well represented in theVallès-Penedès, Castell de Barberà should not be taken as representative of the dominant paleoenvironments in the basin as a whole during this time span—as suggested by differences in faunal composition from the roughly coeval Creu de Conill 20 site, where *Hippotherium* is more abundant (authors' unpubl. data), the micromammal assemblage indicates drier conditions (Casanovas-Vilar et al., 2006, 2008; Casanovas-Vilar and Agustí, 2007), and primates have not been recorded yet (authors' unpubl. data). The rodent assemblage from Creu de Conill 20 is far less diverse than that of Castell de Barberà (Casanovas-Vilar et al., 2006, 2016a, b; authors' unpublished data), and includes few forest-dwelling taxa (*Muscardinus*, cf. *Paraglirulus*), with beavers only represented by scarce remains of *Euroxenomys minutus*. The rodent fauna of Creu Conill 20 is overwhelmingly dominated by the cricetid *Megacricetodon ibericus*, which is very rare at Castell de Barberà and is considered to have been a generalist probably preferring more arid woodlands (Daams and Freudenthal, 1988; Casanovas-Vilar et al., 2006, 2008, 2010, Casanovas-Vilar and Agustí, 2007). At Castell de Barberà, *Eumyarion leemanni* is the most abundant cricetid, which is consistent with the occurrence of locally humid and forested environments.

The dating provided in this paper for Castell de Barberà indicates that renewed efforts are required to better characterize earliest Vallesian faunas from the Vallès-Penedès Basin, not only to investigate the particular conditions that enabled co-existence of hominoids and pliopithecoids, but especially to clarify their taxonomic status and/or phylogenetic relationships. For pliopithecoids, *Barberapithecus huerzeleri* is exclusively known from Castell de Barberà (Alba and Moyà-Solà, 2012). Our results provide an accurate date for this taxon, but additional and more complete material is required to more definitively settle its crouzeliid status and its relationships with other pliopithecoid taxa. Regarding hominoids, attribution of the postcranial remains from Castell de Barberà to *Dryopithecus fontani* by Alba et al. (2011) was only tentative. Given that this taxon is otherwise known only from the late Aragonian of the Vallès-Penedès Basin, France and Austria (Begun, 2002b; Moyà-Solà et al., 2009; Pérez de los Ríos et al., 2013), if such assignment was confirmed then Castell de Barberà might represent the last appearance datum of this genus. However, additional (especially craniodental) remains would be necessary to confirm the taxonomic status of the hominoid taxon recorded at Castell de Barberà, which is intermediate in time between the late Aragonian dryopithecins recorded at Abocador de Can Mata and the more derived hispanopithecins recorded at the basin later during the Vallesian (Alba, 2012; Alba et al., 2017, 2018c).

Two areas of the Vallès-Penedès Basin have the potential to yield additional primate remains roughly contemporaneous with those of Castell de Barberà: the earliest Vallesian site of Creu de Conill 20 in Terrassa; and the Vallesian levels of els Hostalets de Pierola (located westward from Abocador de Can Mata; Moyà-Solà et al., 2009; Alba et al., 2017). The currently available sample of ca. 2000 macrovertebrate remains from Creu de Conill 20 is insufficient to dismiss the ulterior find of primates after additional sampling efforts at this locality (given the rarity of these taxa among Vallès-Penedès fossil assemblages), although the paleoenvironmental hints provided by the recovered fauna are not particularly promising in this regard (see above). This contrasts with the situation in the fossiliferous area of els Hostalets de Pierola, where the presence of an indeterminate dryopithecine is documented close to the Aragonian/Vallesian boundary by a female lower canine from the latest Aragonian fossil locality of Can Mata 1 (Crusafont-Pairó and Golpe-Posse, 1973; Golpe Posse, 1982, 1993; Alba, 2012) and by an isolated upper molar of uncertain provenance from the same area (van der Made and Ribot, 1999; Alba, 2012; Alba et al., 2013). Future fieldwork in these and other sites should help to determine the taxonomic identity of earliest Vallesian hominoids from the Vallès-Penedès Basin and to clarify whether their rare co-occurrence with pliopithecoids at Castell de Barberà and other localities was related to particularly humid and/or densely forested environmental conditions as compared to most other sites from the same basin.

## 5. Summary and conclusions

Here we report new magnetostratigraphic results for the primate-bearing Castell de Barberà site, together with a *Hippotherium* find collected in 2015 from a stratigraphic horizon (CB-D) equivalent to the original main fossiliferous layer at Castell de Barberà. We interpret these data in light of previously published literature and our own review of the rodent assemblage from Castell de Barberà, with the aim of providing an unambiguous and more accurate date for the site.

Our paleomagnetic results, coupled with in situ recovery of a *Hippotherium* humerus, make it unlikely the correlation of any of the various sampled normal polarity magnetozones with the long normal polarity subchron C5n.2n (11.056–9.984 Ma) that is characteristic of the early Vallesian, and support instead correlation of CB-D with C5r.1n (11.188–11.146 Ma), where the Aragonian/Vallesian boundary is situated. Overall, our results unambiguously indicate an early Vallesian age for Castell de Barberà, thereby settling longstanding debate about the Aragonian vs. Vallesian age of this site. Our results further support an earliest Vallesian (~11.2 Ma) age for Castell de Barberà, which would be roughly coeval with the Creu de Conill 20 site, where the first appearance datum of hipparionins in the Vallès-Penedès Basin has been recorded.

Accurate dating of the Castell de Barberà site provided in this paper is important to contextualize the faunal and paleoenvironmental changes that enabled coexistence of pliopithecoids and hominoids at particular sites in the Vallès-Penedès Basin during the late Miocene. It also provides useful hints to redirect future fieldwork efforts in the Vallès-Penedès Basin, with the aim to clarify the taxonomic identity and/or phylogenetic relationships of catarrhine primates that lived there during the earliest Vallesian.

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## Figure captions

**Figure 1.** Fossil primates from Castell de Barberà: the pliopithecoid *Barberapithecus huerzeleri* (A–L) and the large-bodied hominoid (M–O). A–K) IPS1724 (holotype),

selected associated teeth from a single female individual, including the right $I^1$ (A), the left $C^1$ (B), and the left $C_1$ (C), in lingual (left) and labial (right) views, as well as the right $M^1$ (D), the right $M^2$ (E), the right $M^3$ (F), the right $P_3$ (G), the left $P_4$ (H), the left $M_1$ (I), the right $M_2$ (J), and the right $M_3$ (K), in occlusal views. L) IPS1823, male right $C^1$ in lingual (left) and labial (right) views. M) IPS4335, partial distal pollical phalanx, in palmar (left) and dorsal (right) views. N) IPS4333, right proximal pollical phalanx, from left to right in palmar, radial, ulnar, and distal views. O) IPS4334, distal fragment of right humeral diaphysis assigned to cf. *Dryopithecus fontani* by Alba et al. (2012), from left to right in anterior, medial, posterior, and lateral views. Scale bars equal 1 cm, except for O (5 cm). Images are reproduced from previous papers by the authors: L) Alba and Moyà-Solà (2012: Fig. 2); M–N) Almécija et al. (2012: Fig. 1); O) Alba et al. (2011: Fig. 1).

**Figure 2.** A) Aerial photograph of the site of Castell de Barberà (CB), as well as that of the bottom of sections sampled for magnetostratigraphy in this study. Modified from base orthophotos downloaded from VISSIR v3.26 (ICGC, 2018: sheets 288-119 and 288-120, scale 1:5000), ©Institut Cartogràfic i Geològic de Catalunya, with permission from licence Creative Commons (CC) – Attribution 4.0 International (CC BY 4.0; see http://www.icgc.cat/Ajuda/Avis-legal for reuse policies allowed for ICGC web content). B) Detail of Castell de Barberà (Section 2) during the excavation of CB-D (equivalent to the original main fossiliferous layer) in June 2015.

**Figure 3.** Simplified geological map of the Vallès-Penedès Basin. The location of Castell de Barberà is denoted by a black star. Top left inset: location of the Vallès-

Penedès Basin within the Iberian Peninsula. Modified from Casanovas-Vilar et al. (2016a: Fig. 1).

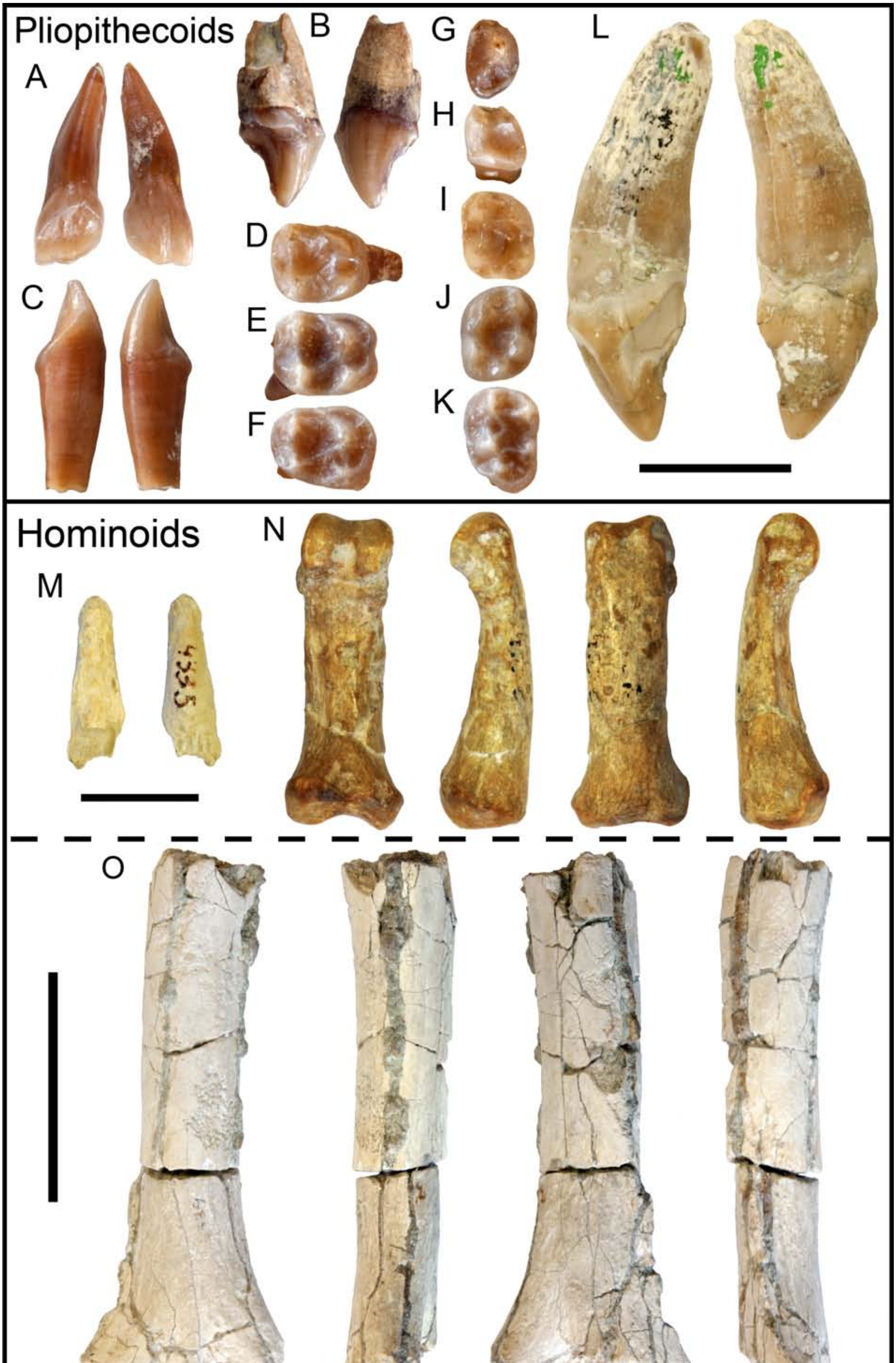
**Figure 4.** Examples of NRM stepwise thermal demagnetization of samples of the Castell de Barberà composite section. Stratigraphic location of samples (uppercase letters) is indicated in Figure 5. Diagrams represent orthogonal projection of vector endpoint demagnetization data; black and white dots represent the projection on the horizontal and vertical planes, respectively. Red lines represent the least-square fit defining the paleomagnetic direction. Q1 and Q2 indicates ranked quality (see SOM Table S1).

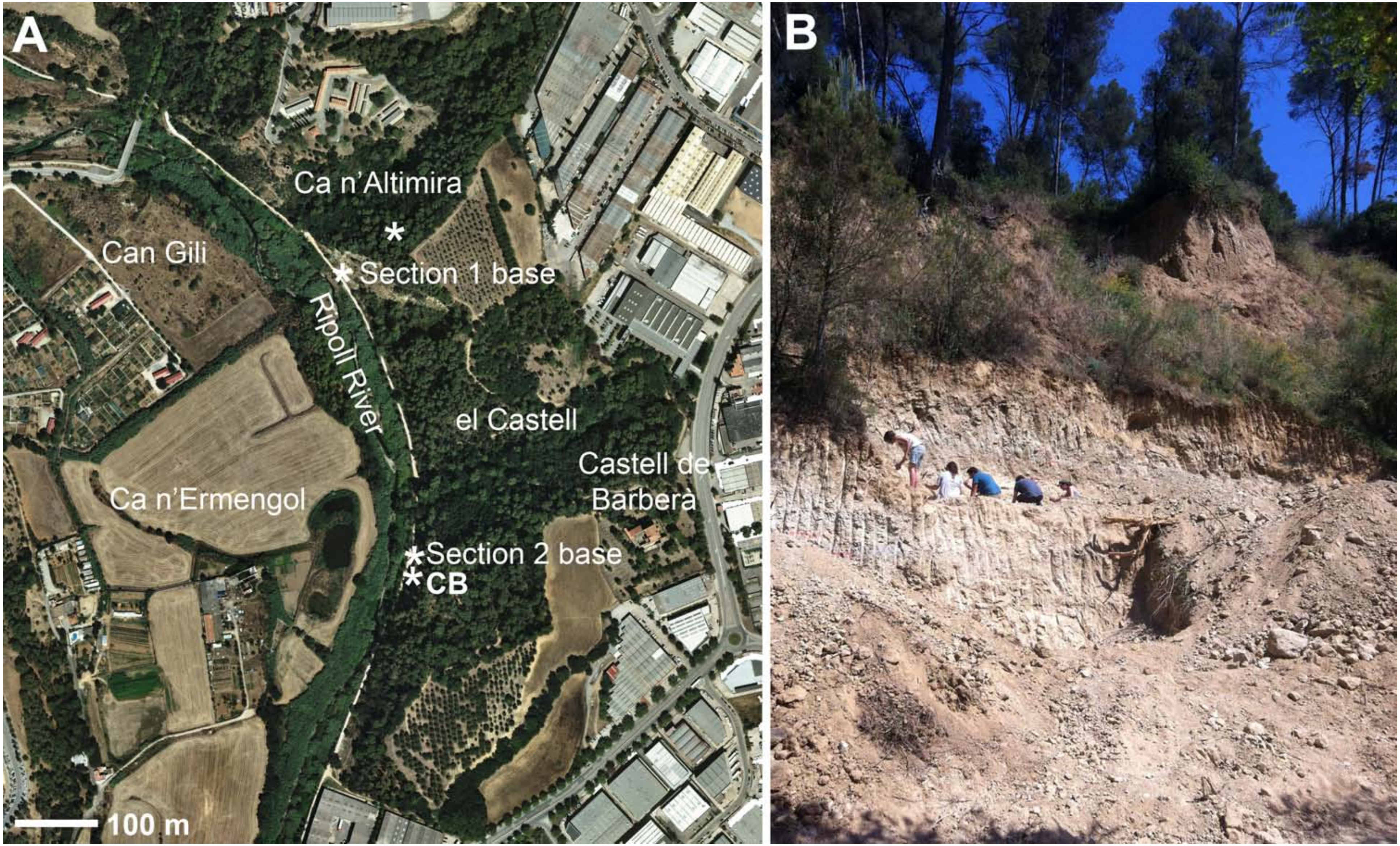
**Figure 5.** Magnetostratigrapic results for the two sampled sections at Castell de Barberà: A) Section 1; B) Section 2, where the site of Castell de Barberà is located. Sideways triangles denote the stratigraphic position of paleomagnetic samples. Red letters and triangles indicate the location of samples from Figure 4. Black circles indicate directions of higher quality (Q1 and Q2), while white circles indicate directions of low quality (Q3)—see SOM Table S1. Abbreviations: c = conglomerates; l = lutites; s = sandstones; VGP = virtual geomagnetic pole.

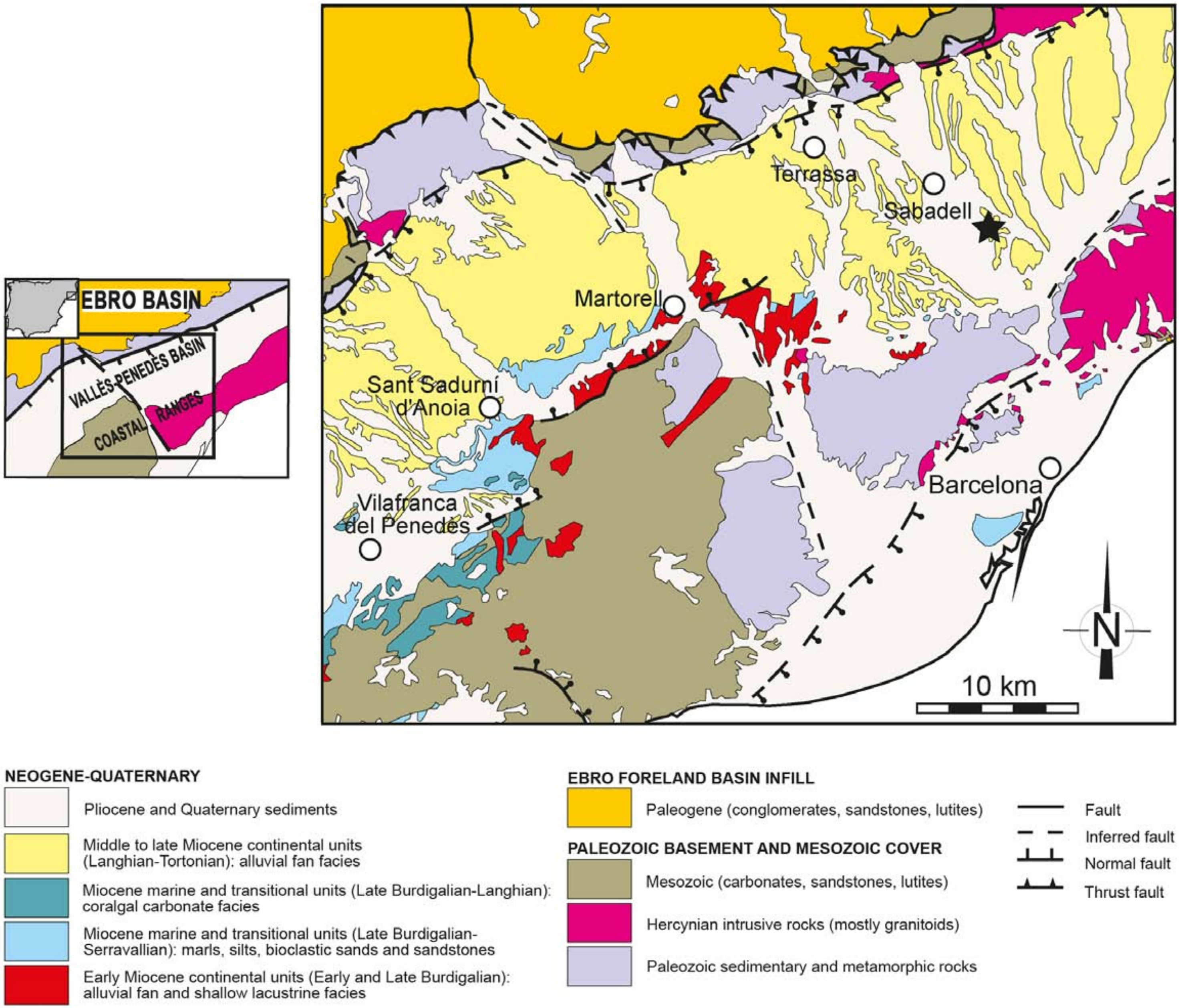
**Figure 6.** Composite local magnetostratigraphic section for Castell de Barberà and its preferred correlation with the geomagnetic polarity time scale (GPTS; Ogg, 2012), as well as European land mammal ages (ELMA), MN (Mammal Neogene) units, and local biozones of the Vallès-Penedès Basin (after Casanovas-Vilar et al., 2016b). See Figure 5 for detailed magnetostratigraphic results of the two sampled sections upon which this composite magnetostratigraphic section is based. Abbreviations: N =

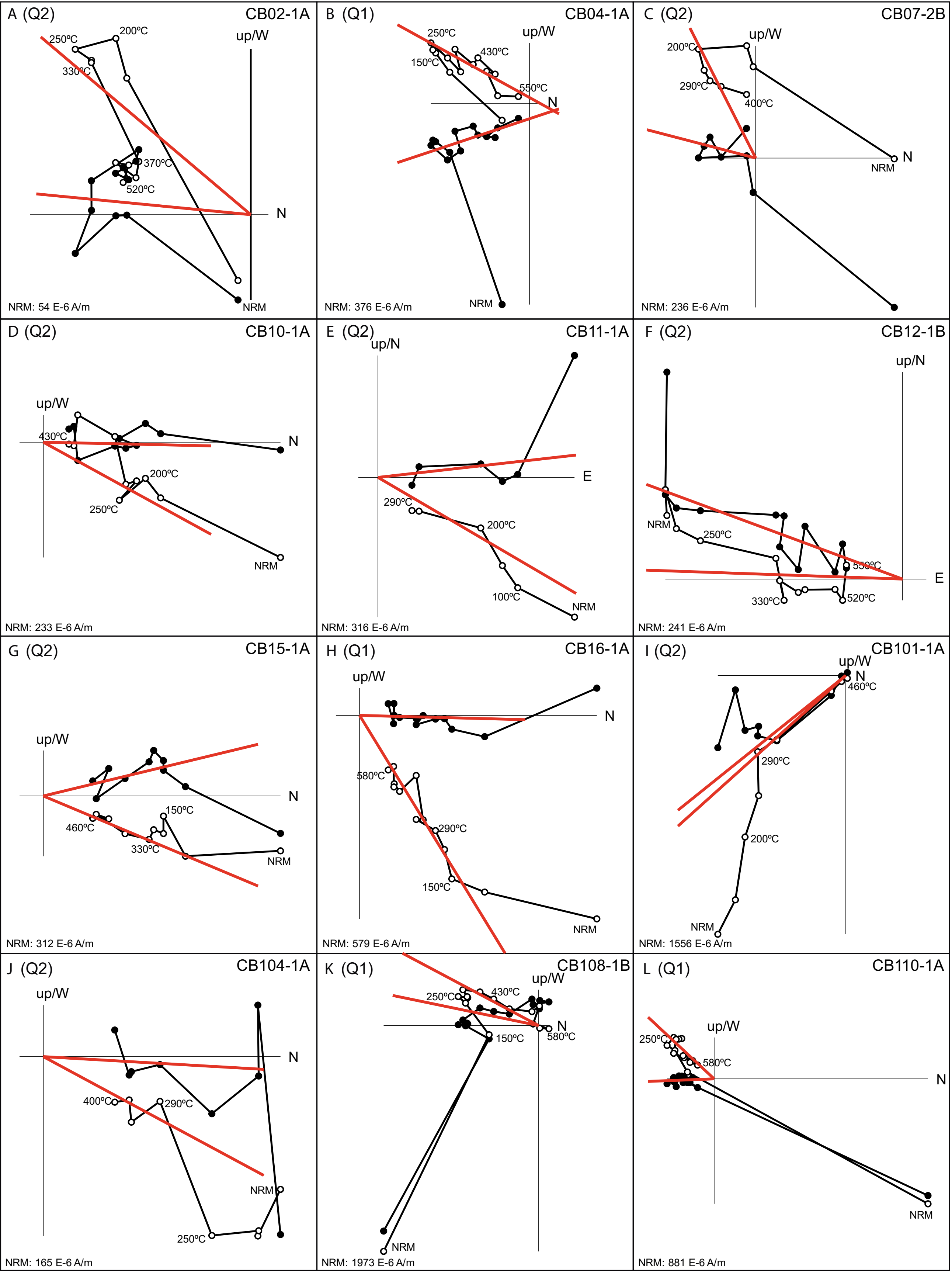
normal polarity magnetozones; R = reversed polarity magnetozones. The arrow next to N2 denotes the stratigraphic position of the main fossiliferous layer of Castell de Barberà (CB-D). Half-width polarity intervals in the GPTS represent short geomagnetic excursions after Evans et al. (2007). Short horizontal lines to the left of the polarity column represent 'tinny wiggles' from the sea floor magnetic anomaly stacks (Cande and Kent 1992), later interpreted as true geomagnetic polarity reversals (Roberts and Lewin-Harris, 2000).

**Figure 7.** Right distal humeral fragment of *Hippotherium* sp. IPS87652 from Castell de Barberà CB-D (equivalent to the main fossiliferous layer) recovered in 2015 (A), compared to those of *Hippotherium catalaunicum* IPS11117 from Can Llobateres (B) and IPS32449 from Polinyà (C, reversed). All specimens are depicted in anterior (left) and posterior (right) views.

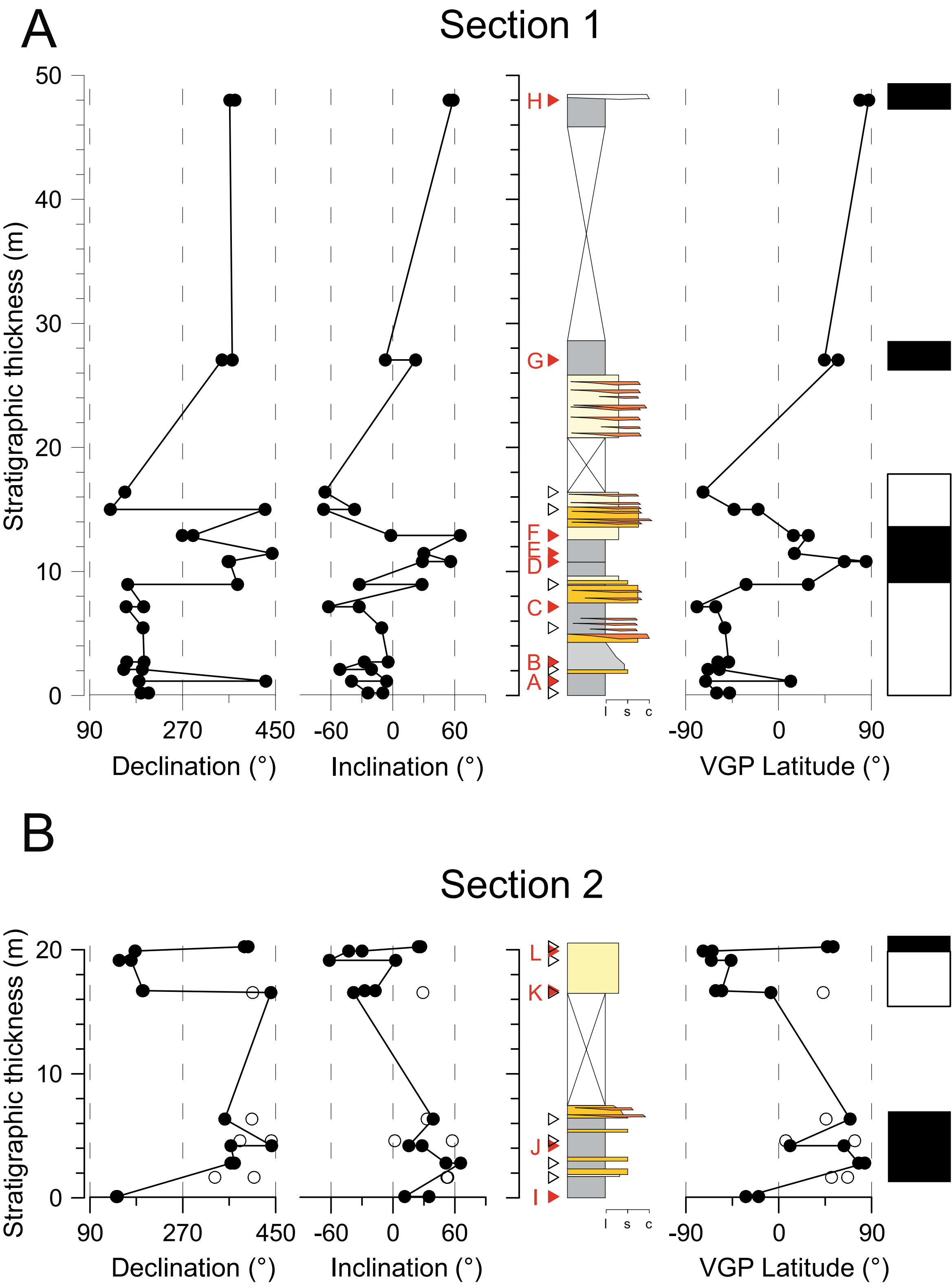

Pliopithecoids
A
B
C
D
E
F
G
H
I
J
K
L
Hominoids
M
N
O

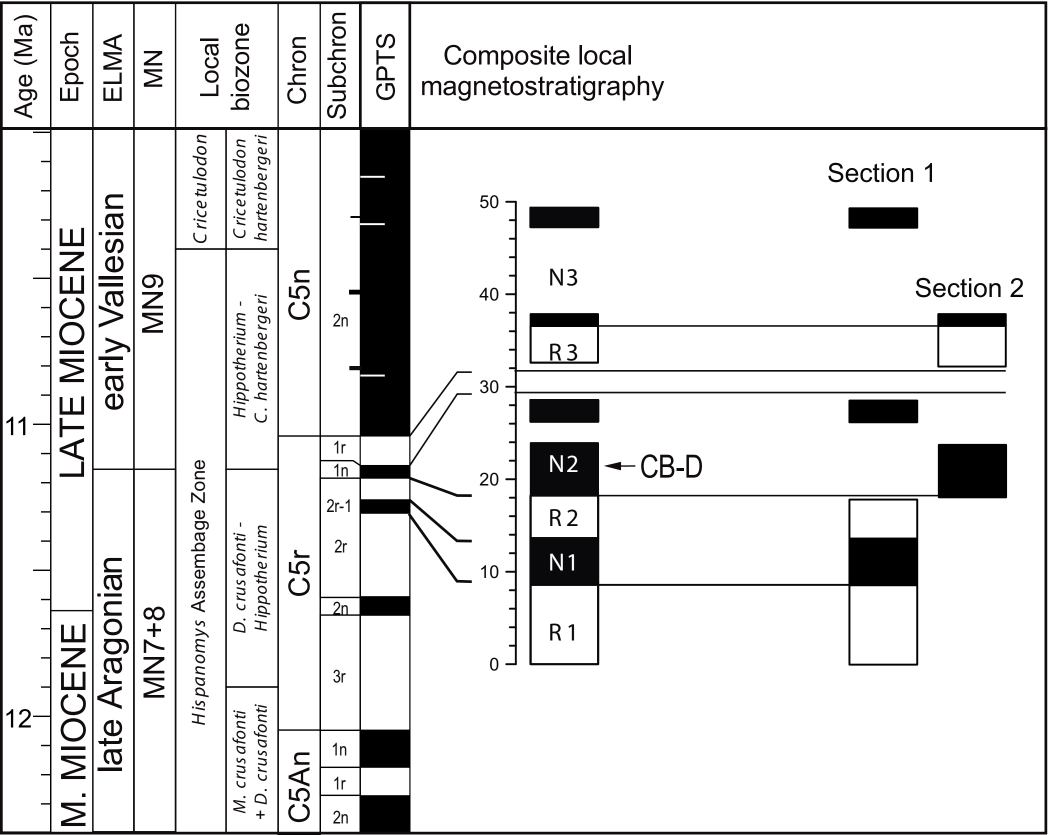

A
Ca n'Altimira
Can Gili
Section 1 base
Ripoll River
el Castell
Castell de Barberà
Ca n'Ermengol
Section 2 base
CB
100 m
B


EBRO BASIN
VALLÈS-PENEDÈS BASIN
COASTAL RANGES
Terrassa
Sabadell
Martorell
Sant Sadurní
d'Anoia
Vilafranca
del Penedès
Barcelona
N
10 km
NEOGENE-QUATERNARY
Pliocene and Quaternary sediments
Middle to late Miocene continental units (Langhian-Tortonian): alluvial fan facies
Miocene marine and transitional units (Late Burdigalian-Langhian): coralgal carbonate facies
Miocene marine and transitional units (Late Burdigalian-Serravallian): marls, silts, bioclastic sands and sandstones
Early Miocene continental units (Early and Late Burdigalian): alluvial fan and shallow lacustrine facies
EBRO FORELAND BASIN INFILL
Paleogene (conglomerates, sandstones, lutites)
PALEOZOIC BASEMENT AND MESOZOIC COVER
Mesozoic (carbonates, sandstones, lutites)
Hercynian intrusive rocks (mostly granitoids)
Paleozoic sedimentary and metamorphic rocks
Fault
Inferred fault
Normal fault
Thrust fault



A (Q2)
CB02-1A
up/W
250ºC
200ºC
330ºC
370ºC
520ºC
N
NRM
NRM: 54 E-6 A/m
B (Q1)
CB04-1A
up/W
250ºC
150ºC
430ºC
550ºC
N
NRM
NRM: 376 E-6 A/m
C (Q2)
CB07-2B
up/W
200ºC
290ºC
400ºC
N
NRM
NRM: 236 E-6 A/m
D (Q2)
CB10-1A
up/W
430ºC
N
200ºC
250ºC
NRM
NRM: 233 E-6 A/m
E (Q2)
CB11-1A
up/N
E
290ºC
200ºC
100ºC
NRM
NRM: 316 E-6 A/m
F (Q2)
CB12-1B
up/N
NRM
250ºC
550ºC
E
330ºC
520ºC
NRM: 241 E-6 A/m
G (Q2)
CB15-1A
up/W
N
150ºC
460ºC
330ºC
NRM
NRM: 312 E-6 A/m
H (Q1)
CB16-1A
up/W
N
580ºC
290ºC
150ºC
NRM
NRM: 579 E-6 A/m
I (Q2)
CB101-1A
up/W
N
460ºC
290ºC
200ºC
NRM
NRM: 1556 E-6 A/m
J (Q2)
CB104-1A
up/W
N
400ºC
290ºC
NRM
250ºC
NRM: 165 E-6 A/m
K (Q1)
CB108-1B
up/W
250ºC
430ºC
N
150ºC
580ºC
NRM
NRM: 1973 E-6 A/m
L (Q1)
CB110-1A
up/W
250ºC
580ºC
N
NRM
NRM: 881 E-6 A/m


A
Section 1
Stratigraphic thickness (m)
0
10
20
30
40
50
90
270
450
Declination (°)
-60
0
60
Inclination (°)
H
G
F
E
D
C
B
A
l
s
c
-90
0
90
VGP Latitude (°)
B
Section 2
Stratigraphic thickness (m)
0
10
20
90
270
450
Declination (°)
-60
0
60
Inclination (°)
L
K
J
I
l
s
c
-90
0
90
VGP Latitude (°)



Age (Ma)
Epoch
ELMA
MN
Local biozone
Chron
Subchron
GPTS
Composite local magnetostratigraphy
11
12
LATE MIOCENE
M. MIOCENE
early Vallesian
late Aragonian
MN9
MN7+8
Cricetulodon
Hispanomys Assembage Zone
Cricetulodon hartenbergeri
Hippotherium - C. hartenbergeri
D. crusafonti - Hippotherium
M. crusafonti + D. crusafonti
C5n
C5r
C5An
2n
1r
1n
2r-1
2r
2n
3r
1n
1r
2n
Section 1
Section 2
50
40
30
20
10
0
N3
R3
N2
CB-D
R2
N1
R1


A
B
C
5 cm

**Table 1**

Updated faunal list of the rodent assemblage from Castell de Barberà.

| Family | Species |
|---|---|
| Castoridae | *Euroxenomys minutus* |
| | *Chalicomys jaegeri* |
| Sciuridae | *Spermophilinus bredai* |
| | *Albanensia albanensis quiricensis* |
| | *Miopetaurista neogrivensis* |
| Gliridae | *Bransatoglis astaracensis* |
| | *Paraglirulus werenfelsi* |
| | *Muscardinus* aff. *sansaniensis* |
| | *Muscardinus hispanicus* |
| | *Myomimus* sp. [a] |
| | *Glirudinus undosus* |
| | *Myoglis meini* |
| Cricetidae | *Anomalomys* sp.[b] |
| | *Eumyarion leemanni* |
| | *Hispanomys daamsi* |
| | *Megacricetodon minutus* |
| | *Megacricetodon* cf. *ibericus*[c] |
| | *Democricetodon brevis nemoralis* |
| | *Democricetodon* cf. *crusafonti*[b] |

[a] Not reported by Casanovas-Vilar et al. (2016b).

[b] New taxa identified from CB, based on the scarce material recovered in 2015: *Anomalomys* sp. c~~C~~omes from CB-~~layer~~ D (equivalent to the ~~classical~~ original main

fossiliferous level), whereas *Democricetodon* cf. *crusafonti* from ~~layer~~ CB-B (~2 m below CB-D) and *Megacricetodon* cf. *ibericus* from ~~layer~~ CB-E (~1 m above CB-D).

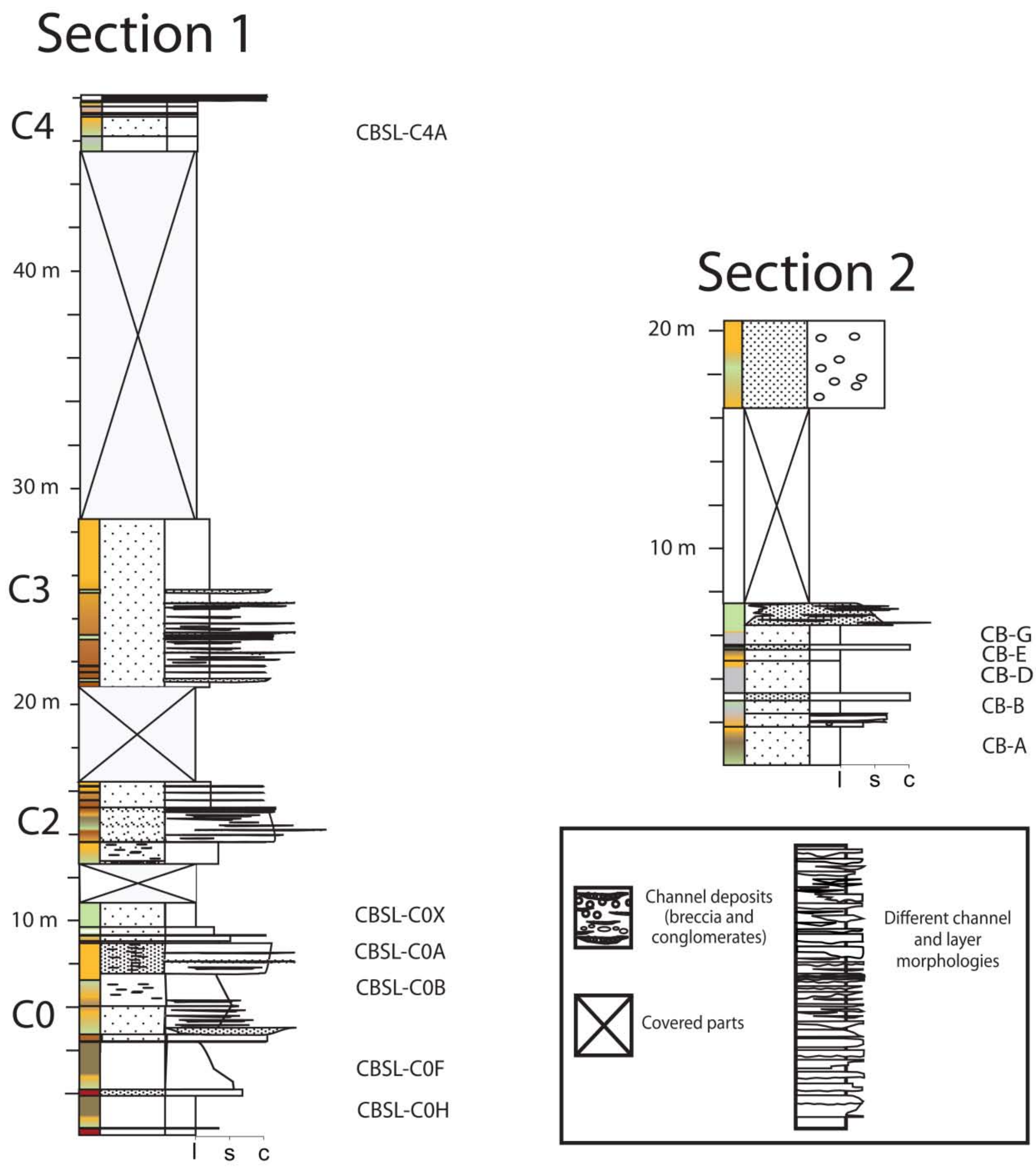
**Supplementary Online Material (SOM):**

Bio- and magnetostratigraphic correlation of the Miocene primate-bearing site of Castell de Barberà to the earliest Vallesian: End of the controversy

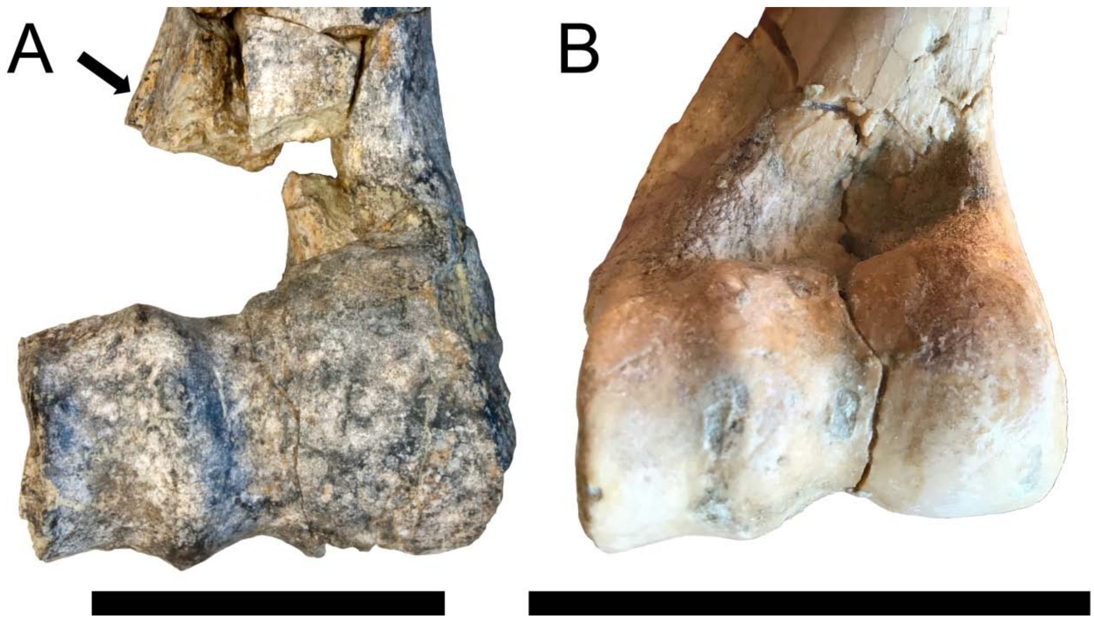
**SOM S1**

**Castell de Barberà stratigraphic profiles**

The stratigraphic profiles performed during the 2014 and 2015 campaigns and their correlation have been depicted in SOM Fig. S1. The various geological layers identified during fieldwork were termed with uppercase letters in each one of the outcrops generated by the digger machine, but these letters have not been indicated in SOM Figure 1, because they are not equivalent between the two sections or even among different outcrops within Section 1. Instead, only those layers that delivered fossils (being considered paleontological localities) have been depicted in SOM Figure S1. The fossil material recovered from Section 1 in 2014 and from Section 2 in 2015 was recorded as coming from the sites of Castell de Barberà s.l. (abbreviated CBSL) and Castell de Barberà (sensu stricto, abbreviated as CB), respectively. Section 1 is composed of four different outcrops (C0, C2, C3, C4) separated by covered portions (note that outcrop C1 is a short section that overlaps with outcrop 0 and yielded no fossils, so it has been omitted from SOM Fig. S1). Section 2, in turn, is composed of two different outcrops that were given no distinct numbers. The exact locality of provenance for each fossil was termed using the abbreviation of the site (see above), followed by a hyphen and an uppercase letter corresponding to the stratigraphic layer; in the case of Section 1, the outcrop number was intercalated before the letter denoting the layer. In Section 1, fossils were recovered from CBSL-C0H, C0F, C0B, C0A, C0X, and C4A (from bottom to top), whereas in Section 2 fossils were found at CB-A, B, D, E, and G (in the same stratigraphic order). CB-D is stratigraphically equivalent to the original layer that delivered most of the fossils from the site.




**SOM Figure S1.** Lithostratigraphic correlation of the two sections of Castell de Barberà excavated in 2014 and 2015. Only those layers that yielded some fossil remains are defined as fossiliferous localities and denoted in the figure (see SOM S1 for further details about their nomenclature)—including CB-D, equivalent to the main fossiliferous layer of Castell de Barberà. Abbreviations: c = conglomerates; l = lutites; s = sandstones.




**SOM Figure S2.** Anterior view of the humerus distal articular morphology of: A) *Hippotherium* sp. IPS87652 from Castell de Barberà CB-D; B) *Anchitherium* cf. *matritense* (without number) from Mahou site (MN5, Madrid Basin). Arrow in A denotes the position of the proximal end of the narrow but deep groove that marks the attachment of the extensor digitorum communis muscle. Specimen in B is from the left side but has been mirrored to ease comparison with IPS87652. Specimens scaled to approximately the same distal width; scale bars = 5 cm. Image B kindly provided by Jorge Morales.

**SOM Table S1**

Calculated paleomagnetic directions from Castell de Barberà sections.

| Section 1 samples | Level (m) | Declination (º) | Inclination (º) | Intensity (E-6 A/m) | Temperature range (°C) | MAD (°) | VGP latitude (°) | Q |
|---|---|---|---|---|---|---|---|---|
| CB01-1A | 0.2 | 204 | -10 | 134 | 370–460 | 1.8 | -47.5 | 2 |
| CB01-1B | 0.2 | 189 | -24 | 84 | 400–520 | 5.8 | -60.0 | 2 |
| CB02-1A | 1.2 | 186 | -40 | 121 | 250–430 | 14.6 | -70.7 | 2 |
| CB02-1B | 1.2 | 431 | -6 | 266 | 290–490 | 7.8 | 11.8 | 2 |
| CB03-1A | 2.1 | 192 | -21 | 100 | 200–370 | 19.4 | -57.4 | 2 |
| CB03-1B | 2.1 | 156 | -51 | 97 | 400–550 | 9.8 | -68.5 | 2 |
| CB04-1A | 2.7 | 162 | -28 | 178 | 250–580[a] | 19.1 | -58.8 | 1 |
| CB04-1B | 2.7 | 195 | -4 | 68 | 400–430 | 3.0 | -48.4 | 2 |
| CB06-2A | 5.5 | 193 | -11 | 245 | 250–370 | 9.9 | -52.0 | 2 |
| CB07-1A | 7.2 | 160 | -33 | 158 | 250–330 | 10.8 | -60.9 | 2 |
| CB07-2B | 7.2 | 195 | -62 | 142 | 200–400 | 10.0 | -79.1 | 2 |
| CB08-1A | 9.0 | 164 | 28 | 83 | 250–370 | 20.6 | -31.4 | 2 |
| CB08-1C | 9.0 | 376 | -32 | 191 | 330–490 | 9.9 | 28.9 | 2 |
| CB10-1A | 10.8 | 361 | 29 | 84 | 250–330 | 6.7 | 63.8 | 2 |
| CB10-2A | 10.8 | 358 | 56 | 72 | 250–330 | 6.9 | 84.9 | 2 |
| CB11-1A | 11.5 | 444 | 30 | 135 | 200–290 | 9.0 | 15.4 | 2 |
| CB12-1A | 12.9 | 269 | 65 | 155 | 250–430 | 8.2 | 28.9 | 2 |
| CB12-1B | 12.9 | 290 | -2 | 163 | 250–550 | 11.5 | 14.4 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CB13-1A | 15.0 | 430 | -67 | 150 | 290–370 | 4.0 | -19.8 | 2 |
| CB13-2A | 15.0 | 130 | -37 | 68 | 370–400 | 8.6 | -43.1 | 2 |
| CB14-1A | 16.4 | 158 | -66 | 85 | 290–400 | 17.1 | -73.2 | 2 |
| CB15-1A | 27.1 | 347 | 22 | 151 | 330–400 | 6.3 | 57.7 | 2 |
| CB15-2A | 27.1 | 366 | -7 | 63 | 330-400 | 5.4 | 44.5 | 2 |
| CB16-1A | 48.0 | 361 | 58 | 293 | 200-580 | 5.4 | 87.4 | 1 |
| CB16-1B | 48.0 | 372 | 55 | 173 | 430-610 | 5.2 | 78.9 | 1 |

| Section 2 samples | Level (m) | Declination (º) | Inclination (º) | Intensity (E-6 A/m) | Temperature range (°C) | MAD (°) | VGP latitude (°) | Q |
|---|---|---|---|---|---|---|---|---|
| CB101-1A | 0.1 | 141 | 35 | 687 | 290–400 | 4.4 | -19.5 | 2 |
| CB101-1B | 0.1 | 143 | 11 | 522 | 250–370 | 17.9 | -31.9 | 2 |
| CB102-1A | 1.7 | 408 | 52 | 95 | 290–370 | 6.3 | 51.2 | 3 |
| CB102-1B | 1.7 | 332 | 53 | 125 | 290–330 | 9.2 | 66.8 | 3 |
| CB103-1A | 2.8 | 363 | 66 | 129 | 290–400 | 1.9 | 83.4 | 2 |
| CB103-1B | 2.8 | 370 | 51 | 161 | 330–430 | 5.9 | 77.5 | 2 |
| CB104-1A | 4.2 | 363 | 28 | 64 | 290–400 | 11.4 | 63.3 | 2 |
| CB104-1B | 4.2 | 442 | 15 | 148 | 250–330 | 5.2 | 11.0 | 2 |
| CB105-1A | 4.6 | 442 | 2 | 106 | 370–500 | 10.7 | 6.8 | 3 |
| CB105-1B | 4.6 | 381 | 57 | 125 | 200–400 | 16.1 | 73.7 | 3 |
| CB106-1B | 6.4 | 351 | 39 | 45 | 330–430 | 22.9 | 69.2 | 2 |
| CB106-1A | 6.4 | 404 | 33 | 80 | 330–450 | 5.2 | 45.9 | 3 |
| CB107-2A | 16.6 | 441 | -38 | 137 | 330–540 | 11.7 | -7.6 | 2 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| CB107-1A | 16.6 | 405 | 29 | 35 | 290–330 | 18.1 | 43.1 | 3 |
| CB108-1B | 16.7 | 192 | -27 | 485 | 370–460 | 6.3 | -61.2 | 1 |
| CB108-1A | 16.7 | 193 | -17 | 84 | 500–580 | 19.0 | -55.3 | 2 |
| CB109-1B | 19.2 | 170 | 3 | 188 | 330–450 | 3.2 | -46.2 | 1 |
| CB109-1C | 19.2 | 147 | -62 | 261 | 250–430[a] | 18.0 | -65.4 | 2 |
| CB110-1A | 19.9 | 178 | -43 | 186 | 290–580 | 8.4 | -73.3 | 1 |
| CB110-1B | 19.9 | 177 | -30 | 639 | 250–450 | 6.5 | -64.5 | 1 |
| CB111-1A | 20.3 | 389 | 27 | 301 | 250–610 | 9.1 | 52.7 | 1 |
| CB111-1B | 20.3 | 397 | 25 | 299 | 250–580 | 7.2 | 47.2 | 1 |

Abbreviations: MAD = maximum angular deviation; Q = Quality rank.

[a] Directions not anchored to the origin.