Response to "Review of "Alluvial record of an early Eocene hyperthermal, Castissent Formation, Pyrenees, Spain""

Louis Honegger et al.

In this response, the original comments are in black and responses by the authors to the reviews are written in blue. Changes in the manuscript are written in red.

We thank Referee #3 for their work and appreciation of our study and the valuable propositions of improvements suggested. We answer below point by point to each item of concern.

1) I think this paper would benefit from a more detailed description of the model used to constrain the age of these deposits. Was the placement of the Castissent Formation within European Mammal Zone MP10 based on the same outcrops sampled here, and if not, what is the proximity of that site? Although the authors state that many of the well-dated sections within the Castissent Formation can be physically correlated to the current study area, how can the authors be confident that these are not time-transgressive deposits? Finally, I am skeptical that the age designation bracket of 50.534-0.025 and 49.695-0.043 Ma can be realistically applied to this unit. That extremely precise age range is based on orbital tuning of a marine record, correlated to a continental record, correlated to the current study area. I am not disputing the correlation, just that the precision of the marine record might not be retained through two iterations of lithostratigraphic correlation.

European Mammal Zone MP10 was found next to the Chiriveta section which is the only direct dating available. A first-hand estimation of the slope of the Castissent Fm. based on grain-size give a slope of $1*10^{-4}$. This would imply a difference of elevation of 1 m between the Campo section (40 km away from the study area, where most of the dating is done) and the Chiriveta section. Considering a mean sedimentation rate of 0.17 m/kyr at the Chiriveta section (this study), it represents a potential lag of ca. 6 kyr between both sections. Therefore, we can make the assumption that the time between upstream or downstream deposition is short enough to not alter significantly the correlation between both sections. Moreover, the correlation of the under- and overlying formations (Castigaleu and Perrarua respectively) adds an additional constraint. A short diachronicity cannot be ruled-out but synchronism on the scale of these two outcrops is a reasonable hypothesis.

We however agree with Referee #3 comments that the extreme age precision from orbital tuning cannot be applied as such for our section. We acknowledge the dating precision of the author in the previous sentence, but ages are rounded up for the Castissent extension. We will change the manuscript accordingly:

*Line 115: "**In the Chiriveta location, stratigraphic constraints are limited to the identification of European Mammals zone MP10 (Badiola et al., 2009), which gives an age range of***

between 50.73 to 47.4 Ma (GTS2012). This age span is refined by bio- and magnetostratiphic data from the Castissent Fm. outcrops of the Campo location, about 40 km further west (Bentham and Burbank, 1996; Kapellos and Schaub, 1973; Payros et al., 2009; Tosquella, 1995; Tosquella et al., 1998) (fig. 3). *Because of its outcropping extent, the Castissent Fm. has been mapped from west to east across these sections (Chanvry et al., 2018; Nijman, 1998; Nijman and Nio, 1975; Poyatos-Moré, 2014)****. The low slope of the Castissent Fm. (ca. 2.3 × 10^{-4} m/m, see supplementary Table S1) indicate an elevation drop of ca. 1 m between the Chiriveta section and the Campo section. Given an average flow depths of 3.75 m in the Castissent channels based on measurement in the Chiriveta and La Roca sections, we thus assume no significant time-lag of deposition between both sections.***

[…]

Line 138: ***Considering the data available and their resolution, we suggest a depositional age span*** *between* ***50.5*** *and* ***49.7*** *Ma for the Castissent Fm (reported in green on Fig. 1)."*

2) The authors note that unlike most marine hyperthermal records, the oxygen and carbon isotopic records are not coupled in the Castissent Formation (the oxygen does not reflect hyperthermal events, whereas the carbon does). Why might this be? Is there evidence of isotopic resetting of the O system (petrographic or other)? How deeply have these rocks been buried? This seems to suggest that even in well-preserved systems, oxygen isotopic records should be used and viewed with caution.

Frequently, oxygen and carbon isotopes are not coupled during hyperthermal events in continental record as already observed by Schmitz and Pujalte, (2003), Bowen et al., (2001) for the PETM. Similarly, small changes in δD are also frequently observed in mid-latitude CIE section (Smith et al. 2007; Tipple et al. 2011). Though the precise mechanisms that produce stable $\delta^{18}O$/δD are still debated, mid-latitude precipitation $\delta^{18}O$ appears to be relatively insensitive to changes in atmospheric pCO_2 and warming, particularly in greenhouse climates (Winnick et al. 2015). Further, the stable $\delta^{18}O$ value (around -5.5‰) throughout the Chiriveta section is likely additionally stabilized by its position close to the coast, which will buffer coastel precipitation $\delta^{18}O$ values relative continental interiors (Kukla et al 2019). This coastal influence is clearly seen in Figure 6 where oxygen isotopes values of the Bighorn Basin have a more continental (i.e., more negative) $\delta^{18}O$ signature then that in the Pyrenees, which is in line with the paleogeography of both basins at the time. This consistency between our results and the ones from the Bighorn Basin suggests a relative good preservation of the oxygen isotopic signal.
However, because sediments from this section might have been buried between 2-3 km and that oxygen isotopes are more prone to diagenesis than carbon oxygen and might therefore not preserve a primary signal, we use them with caution.

The manuscript was modified accordingly:

Line 267:
"Pre-PETM $\delta^{18}O$ values from carbonate nodules from the same area (–4.5 ± 0.4 ‰) (Hunger, 2018) show similar values than the Chiriveta section's measurements (–6.0 ± 0.4 ‰). ***Oxygen and carbon isotopes are not coupled during hyperthermal events in continental record as already observed by Schmitz and Pujalte, (2003), Bowen et al., (2001)*** *for the PETM isotopic excursion.* ***Though the precise mechanisms that produce stable $\delta^{18}O$ during CIE are still***

debated, mid-latitude precipitation δ^{18}O appears to be relatively insensitive to changes in atmospheric pCO$_2$ and warming, particularly in greenhouse climates (Winnick et al. 2015). In contrast*, the* ***stable*** *δ^{18}O value of soil carbonates from the Pyrenean foreland basin (excluding the PETM) (–5.3 ± 0.9 ‰)* ***is likely additionally stabilized by its position close to the coast (****Cerling, 1984,* ***Kukla et al 2019)*** *compared for example to those of the Bighorn Basin (–9.0 ± 0.6 ‰).* ***This is in line with a more continental paleogeographical position of the Bighorn Basin compared to the Tremp-Graus Basin at the time (Seeland, 1998)****."*

Several typographical corrections, sentence reformulations and minor precisions have as well been implemented in this second version of the manuscript. Below are listed the majors ones.

Line 250:

A sub-chapter ***5.1.1 Identifying the CIE*** *was added.*

Line 251:

*"In continental successions, the carbon isotope composition of pedogenic carbonate nodules—which consists of calcareous concretions between 1 mm and 4 cm diameter formed in situ in the floodplain—****have been shown to be sensitive to environmental conditions during their formation (e.g., Millière et al., 2011a, 2011b), and are therefore a promising tool to track how environments respond to carbon cycle perturbation*** ~~*have been proven to reflect global δ13C variations (Abels et al., 2016; Koch et al., 1992; Schmitz and Pujalte, 2003), and may therefore be considered, sometimes together with the oxygen isotope composition (δ18O), as reliable proxy for environmental condition occurring during their formation (e.g., Millière et al., 2011a, 2011b).*~~ *The carbon isotope composition of the soil carbonate nodules depend on the δ13C value of the* ***atmospheric CO2 and*** *soil CO2, which in turn is a function of the δ13C of the atmospheric CO2 ,****and*** *the overlying plants, as well as* ***the*** *soil respiration* ***flux and the partial pressure of atmospheric CO2*** *(Abels et al., 2012; Bowen et al., 2004; Caves et al., 2016; Cerling, 1984). "*

Line 267:

"…nodules, ***which*** *is consistent with* ***a large compilation of data from eastern Eurasia (Caves Rugenstein and Chamberlain, 2018)****"*

Line 302:

"…varies between 0.1-0.29 mm/y, ***consistent with sedimentation rates reported for other Eocene floodplain successions (Kraus and Aslan, 1993)****."*

Line 307:

A sub-chapter ***5.1.2 Mechanisms causing the CIE*** *was added.*

Line 319:

*"**A release of 500 to 1500 Gt of carbon in the form of methane would imply a marine CIE of 0.8 to 2.3‰ or 0.3 to 0.9‰ if the carbon origin is dissolved organic carbon (DOC) (Sexton et al., 2011). The latter seems more plausible regarding the observed amplitude of ~1‰ measured in the marine record for hyperthermal U (Westerhold et al., 2017) and the supposed origin linked to the oxygenation of deep-marine DOC of post-PETM hyperthermals (Sexton et al., 2011). A global shift of -1‰ in δ13C can however not fully explain the 3‰ shift in δ13C observed in this study.** "*