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Discussions

# Interactive comment on "Mammal faunal response to the Paleogene hyperthermals ETM2 and H2" by A. E. Chew

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I wish to preface this with an apology that I was unable to finish and post this response sooner. The concerns raised by Abels and Gingerich were also initially raised by Clyde and addressed first in my response to his review. Clyde's review required extensive consideration and came at a busy time.

Abels and Gingerich present two main criticisms of this project. The first relates to the precision of the stratigraphic correlation that ties the Fifteenmile Creek (FC) fossil framework to the isotope records of the McCullough Peaks. This criticism was also one of Clyde's main criticisms and was addressed extensively in my response to his review. I will recapitulate here: I agree in that I also believe it is impossible to precisely correlate the isotope and fossil sections given available information. It was a mistake

to provide a discussion and "rough correlation" of common biostratigraphic and geo-magnetic events in both areas, my misguided purpose for which was to demonstrate that the CIEs in the McCullough Peaks isotope records and the faunal events described herein occur in common, limited stretches of stratigraphic section (<140 m stratigraphic thickness compared with total section thicknesses >700-3000 m) that document a brief (∼450 ka according to Abels et al., 2012) interval of the early Eocene in the Bighorn Basin. This is not in dispute and I believe the fundamental hypothesis of this paper remains valid but clearly needs to be restated in a way that avoids the misapprehension of it hinging on a precise correlation. To be perfectly clear, I have removed all discussion of, and reference to, the rough correlation I originally attempted to make as outlined in my response to Clyde. I have also explicitly restated my hypothesis along the lines of Clyde and colleagues' work in the McCullough Peaks (Abels et al., 2012) as follows: two faunal events described in the FC section are hypothesized to be related to the McCullough Peaks isotope excursions based on the proximity of the C24r-C24n.3n magnetic polarity reversal and the Wasatchian 4-Wasatchian 5 biozone boundary, and the pattern of faunal change within each event. Within this brief interval of Bighorn Basin time, there were two pronounced CIEs interpreted to represent significant climatic and environmental change AND two pronounced, rapid, and appropriately scaled (in terms of section thickness) events of significant faunal change. The hypothesis that they are related is more reasonable and parsimonious than the alternative, which is that the faunas were immune to the climatic and environmental change indicated by the isotope excursions, instead experiencing within this brief interval two other, unassociated episodes of significant change related to some as-yet unknown external perturbations or to intrinsic controls.

Abels' and Gingerich's subsequent criticisms of the "precise" stratigraphic correlation between the FC and McCullough Peaks sections have been essentially addressed by the revisions laid out in my response to Clyde's review. I will nevertheless respond to their criticisms individually. Abels and Gingerich write "For these correlations, the position of the first normal polarity related to C24n.3n at McCullough Peaks is used, which

is however preceded by an interval of nearly 60m of uncertain polarity at McCullough Peaks. For the correlation, the magnetochron boundary should thus be positioned in the middle of this uncertain polarity interval with ~30 m of uncertainty above and below," In one of the two geomagnetic sections in the south-central part of the Bighorn Basin (Elk Creek Rim local section, Clyde et al., 2007), the shift to C24n.3n occurs in an analogous zone of ~30m of uncertain polarity. Both zones encompass the H2 CIE and the B-2 faunal event and do not alter the clear proximity of this geomagnetic event to them.

Abels and Gingerich continue: "In the correlations made by Chew, ETM2 and H2 are placed between 410–420 m and between 430–440 m, respectively. This results in sedimentation rates of 0.165 m/kyr at Fifteenmile Creek." Here, Abels and Gingerich seem to imply that I have calculated a sediment accumulation rate of 0.165 m/kyr between the roughly predicted levels of the McCullough Peaks CIEs in the FC section, which would indeed be misguided. I hope it is clear from my preceding discussion (lines 12-18, p. 1375) that the tie points used in the calculation of the average sediment accumulation rates are the PETM, the C24r-C24n geomagnetic polarity shift, and a volcanic ash in the FC section, with numerical ages (56.33, 53.57, and 52.9 Ma, respectively) from Tsukui and Clyde (2012). The 0.165 m/kyr sediment accumulation rate is an average over ~450 meters of stratigraphic thickness from the PETM to the C24r-C24n geomagnetic polarity shift. In the next paragraph (lines 16-17, p. 1376), I point out that there is "variation in sediment accumulation rates [in the FC] over time, especially around Biohorizon B (Bown and Kraus, 1993; Clyde, 2001)." This variation is described in Bown and Kraus (1993: p. 73) as follows: "The paleosol data indicate relatively low rates of sediment accumulation in the southern Bighorn Basin at the onset of Willwood deposition, and a general increase in these rates through time (Fig. 4, right column). That this increase was relatively constant is shown by the more or less continuous decline in maturation indices through time; however there were significant punctuations of this trend. These occur in the 75-150 m, 200-250 m, 375-425 m and 600-625 m intervals." The third of these punctuated episodes of increasing sediment accumulation

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rate encompasses Biohorizon B and faunal event B-1. From Fig. 6 in Bown and Kraus (1993), it is apparent that the highest rates of FC sediment accumulation occur above this punctuation (i.e., after faunal event B-1) and continue up to the top of the section. This variation, averaged over several hundred meters of section, severely limits the utility of the 0.165 m/kyr sediment accumulation rate in reconstructing time in this part of the FC section.

Abels and Gingerich use the 0.165 m/kyr sediment accumulation rate to extrapolate a sediment accumulation rate in the McCullough Peaks that is too low, but it is based on the flawed (as I myself have demonstrated in this paper) correlation between the McCullough Peaks and FC sections: "A scaling factor of 0.68 implies a McCullough Peaks sediment accumulation rate 47% higher (1/0.68 = 1.47) than that at Fifteenmile Creek. The accumulation rate at McCullough Peaks would then be 0.243 m/kyr. However, the mean accumulation rate for McCullough Peaks, based on all information available previously, is 0.329 m/kyr (Abels et al. 2013, Table 1)." I leave aside their discussion of the temporal separation between the predicted levels of the McCullough Peaks CIEs in the FC section, again given that these predictions were flawed (as I myself demonstrated in the paper). Finally, Abels and Gingerich proceed to use the 0.165 m/kyr sediment accumulation rate to extrapolate a separation of ~181 kyr between faunal events B-1 and B-2: "The B-1 and B-2 events are however tied to diversity peaks at about 410 and 440 m, respectively, meaning that they are separated by about about 30 m and 181 kyr. Both separations at Fifteenmile Creek are substantially longer than the 100-kyr eccentricity-cycle spacing of the ETM2 and H2 hyperthermals." In fact, this overestimation is to be expected, given the marked acceleration in sediment accumulation rate near the beginning of, or between, faunal events B-1 and B-2. I did not go into accumulation rates and the temporal separation of faunal events B-1 and B-2 in the paper because I thought it was apparent from the published work describing rate variation, especially around Biohorizon B, that this exercise would be futile. To be absolutely clear, I have added "although variation in sediment accumulation rate, particularly in this part of the FC section (Bown and Kraus, 1993), severely limits the utility of such

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estimates" to the end of the last sentence in the first paragraph of the methods (lines 22-24, p. 1375). I have also removed the estimates of event durations based on the 0.165 m/kyr sediment accumulation rate from the first paragraph of the Results section (p. 1381-1382) and removed the absolute ages from the scale bar in Fig. 2 in order to eliminate any misleading impression of reliance on this rate.

The second main criticism in the Abels and Gingerich review relates to sampling bias and was also raised by Clyde in comments pertaining to Fig. 2, which I addressed in related revisions to Fig. 2 and Fig. 4 and a paragraph added to the Results section beginning on line 25, p. 1382. Although Abels' and Gingerich's concerns have been essentially addressed by those revisions, I will respond to their criticisms individually. Abels and Gingerich write "These are the two narrow stratigraphic intervals that have yielded some 15–20 times more specimens than others in the broader Fifteenmile Creek interval being correlated to McCullough Peaks." I do not deny that there is great sampling discrepancy. It is why I instituted such exhaustive standardization procedures (binning, resampling, rarefaction, instantaneous, per-taxon rates, etc.). Nevertheless, Abels and Gingerich exaggerate. The "narrow stratigraphic intervals" documenting faunal events B-1 and B-2 are each ~13 meters thick and their average sample size (3728 specimens) is seven times greater than the average sample size (506 specimens) of all 13-meter intervals in the series beginning directly below faunal event B-1 (range of 4-9 times greater for all but two of the individual 13-meter intervals below faunal event B-1). The average sample size of the B-1 and B-2 intervals is twice that of the 13-meter intervals between them (1959 specimens), and the average sample size of all 13-meter intervals in the series beginning directly above faunal event B-2 (4746 specimens) is actually 30% larger than the average sample size of the B-1 and B-2 intervals. All but one of the 13-meter intervals above faunal event B-2 is between 1.2 and 1.8 times greater than the average sample size of the B-1 and B-2 intervals. From this, it should be clear that there is a long-term trend of increasing sample size of which faunal events B-1 and B-2 are part. As indicated in my response to Clyde's review, I have added the entire sampling distribution of the binning series to Fig. 2, which demonstrates this

variation more clearly.

Abels and Gingerich continue: "A discrepancy in sampling this large is difficult to overcome statistically because standardized comparison requires degrading the better samples for comparison with the poorer ones, and the poorer samples in this case are biased in lacking many of the smaller and rarer taxa that only appear when samples are large." Yes, this is unfortunately necessary and the explicit point of the resampling and rarefaction techniques used in this paper. The alternative is that paleoecological (or other) analysis can only be done when all samples are equally well (or poorly) represented, which is not practical in paleontological scenarios. The FC fossil record is widely regarded as exceptional. I am not aware of any better records with which to attempt just such an analysis as this. Abels and Gingerich continue: "The intervals identified as B-1 and B-2 are exceptionally fossiliferous, have been more intensely sampled than other intervals, or both (collectors naturally focus on productive intervals). B-1 and B-2 stand out for being rich and well sampled, but this does not make them biotic events. And the presence of two rich, well-sampled intervals at Fifteenmile Creek does not mean the intervals coincide with ETM2 and H2." I have demonstrated that the B-1 and B-2 intervals are not exceptionally fossiliferous relative to the intervals above, and are clearly part of a long-term trend of increasing sample size. In my response to Clyde's review and related revisions, I have further demonstrated that the standardization techniques used in this paper were adequate to remove sample size bias from the averaged, binned paleoecological parameters.

Abels and Gingerich conclude: "The new postulates, that ETM2 was the driver of B-1 and that H2 was the driver of B-2, are testable hypotheses, but the postulates will only be tested when ETM2 and H2 $\delta$13C anomalies are found in the same stratigraphic section as B-1 and B-2. Pending documentation of the ETM2 and H2 $\delta$13C anomalies at Fifteenmile Creek, it seems too premature to claim B-1 and B-2 as faunal responses to the hyperthermals ETM2 and H2." As previously stated, I have explicitly restated my hypothesis as follows: two faunal events described in the FC section are hypothesized

to be related to the McCullough Peaks isotope excursions based on the proximity of geomagnetic and biostratigraphic events, and the pattern of faunal change within each event. Within a brief (∼450 kyr) interval of Bighorn Basin time, there were two pronounced CIEs interpreted to represent significant climatic and environmental change AND two pronounced, rapid, and appropriately scaled (in terms of section thickness) events of significant faunal change. The hypothesis that they are related is more reasonable and parsimonious than the alternative, which is that the faunas were immune to the climatic and environmental change indicated by the isotope excursions, instead experiencing within this brief interval two other, unassociated episodes of significant change related to some as-yet unknown external perturbations or to intrinsic controls. Abels and Gingerich suggest that this hypothesis is not sufficiently supported without directly-related isotope data. I argue that directly-related isotope data would constitute a critical test of the hypothesis presented herein, but such data are not currently available.

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Interactive comment on Clim. Past Discuss., 11, 1371, 2015.