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Interactive comment on "Orbital forcing of terrestrial hydrology, weathering and carbon sequestration during the Palaeocene-Eocene Thermal Maximum" *by* Tom Dunkley Jones et al.

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From the replay of Tom Dunkley Jones et al. to my first Comment it seems that I failed to convey a clear picture of my view of the early Paleogene evolution of the Basque Basin. Further, Tom's replay and the Comments by Michael Clare, have raised new relevant questions. In this second Comment I try to clarify my view and answer the new questions.

1. Sedimentation during the PETM differed fundamentally from that prevailing during the Paleocene.

As I pointed out in my first Comment, during the early Paleogene the Basque Basin accumulated both autochthonous and allochthonous deposits. The former are represented by hemipelagic deposits (mainly calcareous), the latter by both calciclastic and siliciclastic deposits. The calciclastics were sourced from the carbonate platform immediately girding the basin, the siliciclastics from the mountains situated further out (i.e, "topography" in supplementary Fig. 1).

During Paleocene times the sedimentation was dominated by calcareous deposits (supplementary Fig. 2): calciclastic breccias and thick-bedded calciclastic turbidites were accumulated in base-of-slope aprons just off the carbonate platform margin, as typified by the Ermua and Aixola sections (supplementary Figs. 3−5), while stacks of hemipelagic deposits, with and without intercalated thin-bedded calciclastic turbidites, were deposited on the basin floor.

The PETM brought about a radical sedimentological change, most likely as a result of an abrupt hydrological change (Schmitz et al., 2001; Schmitz and Pujalte, 2007), recorded by a massive input of fine- and coarse-grained siliciclastic deposits. As reported by Pujalte et al. (2015 and 2016), and illustrated in supplementary Fig. 2, the coarse- and fine-grain populations became everywhere separated. In the shallow marine domain siliciclastic sands and gravels were accumulated in local braid deltas at the mouth of incised valleys, while fine-grained silts and clays were widely distributed by longshore currents. As a result, most of the Paleocene carbonate platform became mantled with siliciclastics, a fact resulting in a reduction of carbonate production and export to the basin (Pujalte et., 1998a). The massive siliciclastic input also reached the Basque Basin, delivered by turbidite currents and underflow plumes: the bulk of coarse-grained siliciclastic deposits were stored in the axial part of the deep-sea channel (supplementary Fig. 6A), while most of the fine-grained clays became widely distributed over the basin floor (supplementary Fig. 2). In addition, as exemplified by the Barinatxe section (see my first Comment), both coarse- and fine-grained siliciclastics were deposited in the shoulders of the deep-sea channel.

As indicated in my first Comment, and illustrated in Fig. A, autochthonous hemipelagic deposits can be correlated bed to bed across the entire basin (and further out). This fact entails that the control on hemipelagic deposition can be confidently ascribed to an external sedimentary forcing, which several papers have demonstrated to be Milankovitch precessional cyclicity (e.g., Dinarès-Turell et al, 2014, and references therein).

In contrast, as mentioned also in my first Comment, the amount of allochthonous deposits varied greatly between different sections, an indication of random distribution. The stochastic vertical arrangement of the allochthonous PETM deposits can be visualized, for example, at the Barinatxe section (Fig. B).

2. Completeness of the PETM at Zumaia

Prior studies across the P–E boundary interval at Zumaia have not recognized any biostratigraphic gap (e.g., Schmitz et al., 1997; Orue-Etxebarria et al., 2004; Alegret et al., 2009). This indicates that the interval is quite complete, but it does not necessarily demonstrate that sedimentation was continuous at Zumaia during the PETM, since the resolution of biostratigraphic zonation is too low to detect small hiatus(es). So, it remains to be proved that sedimentation was continuous during the SU, and whether or not the Si/Fe cycles reported by Dunkley Jones et al. are real or an statistical artefact.

Incidentally, the authors have identified similar Si/Fe cycles throughout the whole studied interval. However, the cycles below and above the PETM are attributed to the precession, while the 10 cycles within the SU are “most likely half-precession cycles”. It is not clearly stated in the original manuscript, but it looks as if the authors have attributed these 10 cycles to half-precession cyclicity so that their total duration fit the accepted age of the PETM. If so, this would look a bit like circular reasoning. In conclusion, unless the authors can convincingly prove that their Si/Fe half-precession cycles are real, I recommend that they make use of averaged sedimentation rates to back their proposed model of the timing of the climate and CIE recovery from peak-PETM conditions.

3. Turbidity activity at Zumaia during the PETM.

Dunkley Jones, quoting Clare et al. (2015), indicates in his Reply that: "I refer reviewers and readers to this article, but the main conclusion is that there is a significant turbidite "switch-off" precisely correlated with the PETM event at both Zumaia and ODP 1068." Indeed, Clare et al. (2015) concluded that "The frequency of turbidity current activity is reduced significantly at the IETM [alternate name for the PETM]. This includes a cessation of turbidity currents during the rapid warming phase..."

I do not know about the ODP Site 106, but I maintain that the frequency and intensity of turbidite activity in the Basque Basin greatly increased during the PETM.

The main problem with the proposal of Clare et al. (2015) is that it does not take into account the fundamental change of sedimentary conditions induced by the PETM. In this respect, it is important to note that most, if not all, the turbidites intercalated within the pre-PETM hemipelagic succession at Zumaia have a calciclastic nature, a proof that they were derived from the surrounding carbonate platform. In any case, their recurrence time was very low. In effect, only 22 turbidite beds, most of them ∼1 cm thick, are intercalated in the seven precession-paced marl/limestone couplets situated just below the green limestone (2000). A simple calculation shows that turbidite recurrence time in pre-PETM times was around 6,5 kyr.

Calciclastic turbidites are indeed absent in the SU itself, the reason for which is explained below. But it is logical to conclude, from the observations in the Barinatxe section (Fig. B), that the accumulation of the SU at Zumaia resulted from a high number of small-scale depositional events, probably driven by underflow plumes or very diluted turbidites.

The enhancement of turbidite frequency during the PETM can best be assessed at the Ermua and nearby Aixola sections, both situated at the base-of-slope apron (for location see Pujalte et al., 1998b). In these two sections the Paleocene is represented by a stack of carbonate breccias and thin and thick-bedded calciturbidites, some of them more than 4 m thick (supplementary Figs. 3–5), which in all probability are the proximal equivalent of the thin-bedded turbidites at Zumaia. About 150 turbidite events are counted in the detailed log of the Aixola section (supplementary Fig. 5) which, since the Paleocene Epoch spans ∼10 Myr, would imply a recurrence time of 65 kyr. Such figure, however, is clearly too low, and proves that a large number of turbidites must be missing at Aixola, as demonstrated by the existence of several important erosional surfaces in the succession (supplementary Fig. 5). But it is clear, in any case, that recurrence time for turbidite deposition must have been very low during Paleocene times.

In contrast, no less than 70 thin-bedded calciclastic turbidite beds are intercalated in the well exposed upper 9 metres of the PETM at Ermua (Fig 3C), from which it can be estimated that the whole 20 m thick PETM interval may contains up to 175 turbidites. The duration of the body of the PETM is estimated in âĹij113 kyr (e.g., Murphy et al. 2010), which implies that averaged recurrence time of the turbidite activity at Ermua during the PETM was about 0.65 kyr. Further, the small volume of these turbidites, which can be ascribed to the low productivity of the coeval carbonate platform, explains why no calciclastic turbidites reached Zumaia during the PETM.

The coarse-grained siliciclastic deposits from the axis of the deep-sea channel provide an indication that the strength of the turbidite currents also increased in the channel during the PETM. Thus, at Orio pre-PETM turbidites are represented by plane-parallel sandy turbidites, 0.5–1m thick, separated by laterally continuous 1–2 cm thick clay drapes (Pujalte et al. 2015, Fig. 10d). In contrast, the PETM interval is made up of amalgamated sandstones and pebbly sandstones, the latter with clasts up to 3 cm in diameter (Pujalte et al. 2015, Fig. 10g). They occur in beds ranging 2–4 m in thickness, as a rule separated by concave-up erosional surfaces indicative of frequent cut-and-fill processes. These same features can be observed in the PETM siliciclastic turbidites from the Urduliz section (supplementary Fig. 6).

Figures mentioned in the text.

Fig. A. Close-up of a segment of the lower part of the hemipelagic Danian limestones from Sopelana(N Spain) and Hendaia (SW France). Note the exact correspondence of the marl/limestone couplets from both sections, which are situated about 100 km apart. (Reproduced from Fig. 7 of Pujalte et al, 1998b).

Fig. B. A close-up of the fine-grained siliciclastic deposits at Barinatxe. The pen in the photo is 14 cm long, the stacked fining-upward packages range from 1 to 3,5 cm in thickness, indicative of small depositional events of variable magnitude. Note also the discontinuous lateral extension of the quartz-rich basal parts of the packages.

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Please also note the supplement to this comment:
https://www.clim-past-discuss.net/cp-2017-131/cp-2017-131-RC4-supplement.pdf

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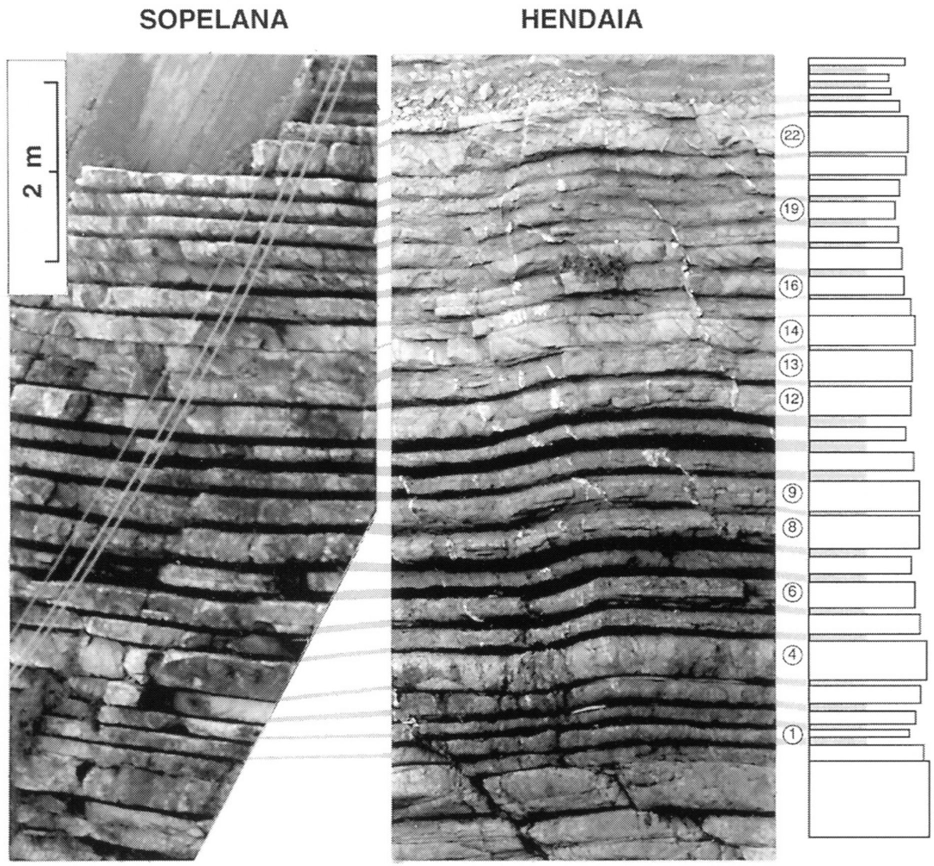

Fig. 1.

Fig. 2.

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