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Biogeosciences Discussions

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Interactive Comment

Interactive comment on "Equatorial Pacific peak in biological production regulated by nutrient and upwelling during the late Pliocene/early Pleistocene cooling" *by* J. Etourneau et al.

J. Etourneau et al.

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Firstly, we would like to extend our thanks to G. Filipelli and C. Bolton for their helpful and constructive comments.

Please see below the responses to the points underlined by the reviewers.

Reviewer 1: G. Filipelli Response: The reviewer is perfectly right, phosphorus (P) limitation is not addressed in this manuscript as we are not able to provide such long-term records. Dekens et al. (2007) reported phosphorus mass accumulation rate (MAR) records spanning the last 5 Myr. Unfortunately, these records were restricted to the California and Peru margins, while it would be of primary interest to obtain similar records in the EEP. In this article, the authors show a close link between export production and P MAR evolution, thus suggesting a strong relationship between P supply and biological production. According to our results, the denitrification in the eastern Pacific was weaker between 3.2 and 1.6 Myr, prior to increasing through the Pleistocene (also see Robinson et al., in review) which suggest higher nitrate availability in the surface water until the high export biological production decline. If nitrate supply exceeded its demand during the late Pliocene-early Pleistocene cooling, then the NO3:PO4 ratio may have increased. However, this higher ratio might be counteracted by enhanced P supply from a more humid-than-today continent and increased continental weathering carrying significant P into a warm EEP. This would have indeed favored net production. In contrast, increasing denitrification from 1.6 Myr would have reduced the nitrate availability, thus resulting in a lower NO3:PO4 ratio. However, this ratio might have remained stable when considering a drier western South America margin owing to an extensive cold tongue and a switch from El Nino-like to La Nina-like conditions. This would have led to reduced drainage of P into the cold EEP, and in addition to nitrate, P might have been an additional factor controlling biological activity and participated to the biological productivity collapse. However, there is no evidence in the EEP on P records and/or modeling studies. Yet, there is no evidence from other nutrient control, especially silicic acid for siliceous producers. We really hope that in the near future, P and d30Si records will be traced in the EEP covering the Pliocene-Pleistocene climate transition. We mention in the text, at the end of the discussion section, the need to provide such record in the near future.

Reviewer 2: C. Bolton

Comment 1: Given that there is good age control at both sites, the authors should consider plotting C37 concentration, % N and % TOC records as mass accumulation rates because variations in accumulation rates are a more accurate reflection of biogenic material fluxes to the sea floor. Does this alter long-term export productivity trends?

Response: we did consider plotting all paleoproductivity records as mass accumulation

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rates (MAR), the MAR corresponding to: MAR (g/cm2/kyr) = LSR (Linear Sedimentation Rate (cm/kyr)) x DBD (Dry Bulk Density) x Component percentage/100. However, the sedimentation rate (SR) is too influential on our proxy records, the LSR being largely greater than component percentage (alkenone concentration, TN or TOC), and significantly alters export productivity trends. For instance, the peak in export productivity is by far less pronounced between 2.2 and 1.6 Myr and was more significant around 3.0 Myr, broadly similar to the SR profile (Figure 1 attached). It does not make sense when regarding the existing records from the EEP area which reports exactly the same trend in alkenone concentration – not MAR – than our EEP Site 1239 record (e.g. Site 846, Lawrence et al., 2006), and show general agreement with variations in other paleoproductivity indices (e.g., biogenic opal content (Mix et al., 1995)). Furthermore, all the independent proxies (TOC, TN and alkenone concentration) used for paleoproductivity reconstruction points to the same profile. We therefore believe as now clarified in the text (L.144-146, p.5) that our records as content are not significantly affected by preservation, dilution or concentration effects and mostly reflect past export production changes. In order to give further explanations in the text, we now include a paragraph: "TN and TOC represent the overall phytoplankton production, while C37 concentration reflects changes in alkenone producers, most probably Reticulofenestra species (Bolton et al., 2011). Changes in preservation, dilution, and concentration might affect the paleoproductivity signal traced by the different proxies. The mass accumulation rate (MAR) of sediment constituent is commonly applied to estimate past export productivity fluxes. However, although the age model at our EEP sites is well constrained, the use of MAR instead of content can be largely uncertain regarding the export productivity produced in the subsurface waters (François et al., 2004). In addition, the carbonate (CaCO3) content does not vary significantly since 3.0 Myr (Mix et al., 2003), implying that changes in dilution or concentration of the other - more minor biogenic components by carbonate fluctuations - are not driving the fluctuations of the records. The exception may be during the high TOC/TN/C37 interval, where CaCO3 content decreases slightly (Mix et al., 2003). This probably represents

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a decrease in CaCO3 preservation due to high TOC delivery, but it was relatively minor compared to the high productivity-related concentrations peak centered between 2.2-1.6 Myr. Therefore, preservation effects did unlikely play a significant role on controlling the paleoproductivity signal. This is further supported by similar variations in export productivity reconstructed at all EEP sites (e.g. Dekens et al., 2007; Lawrence et al., 2006). In addition, a recent work based on paleoproductivity reconstructions in this region spanning the same time interval reported consistent variations between the C37 concentration and independent floral data (Bolton et al., 2011)."

Comment 2: Focus on 2.2-1.6 Ma The current manuscript is primarily focused on understanding the EEP export productivity peak between 2.2 and 1.6 Ma. In this interval, low SSTs, high C37, TOC and TN contents, and low d15N are interpreted together as showing an increase in upwelling and low relative nutrient utilisation (here interpreted as an increase in nutrient supply rather than a decrease in consumption). This interpretation of the proxies for the interval 2.2-1.6 Ma is internally consistent and makes sense. However the authors make no attempt at understanding in the above terms what is happening between 2.9 and 2.4 Ma. In this interval, their records from Site 1239 show: (1) High C37 concentrations (some peaks in this interval are higher than in the interval 2.2-1.6 Ma). High alkenone content in this older interval is also seen in the Site 846 record. (2) Low d15N (similar to d15N in the interval 2.2-1.6 Ma, therefore also suggestive of low relative nutrient utilization) (3) Medium to low TOC and TN % (significantly lower than in the interval 2.2-1.6 Ma, but slightly higher than during the interval 1.6-0 Ma). (4) Relatively warm SSTs (suggestive of low upwelling intensity compared to the interval 2.2-1.6 Ma, or warm upwelled waters). I think some discussion of what the proxy records suggest for this interval would be appropriate and also interesting. In this context, some discussion of the origin of the different proxies presented could be included and might help with the interpretation (for example, alkenones are exclusively from coccolithophores, TOC originates from all exported production, d15N reflects N usage by all primary producers(??)). Do shipboard records of CaCO3 versus opal accumulation provide any clues as to which groups were dominating primary production during the interval 2.9-2.4 Ma versus 2.2-1.6 Ma? In this context, the statement line 14 page 5543 "Prior to the event, between 3.2 and 2.2 Myr, export production was overall low while d15N values were relatively high and variable" is not really true for Site 1239.

Response: the focus of this manuscript is to investigate the causes of the elevated export production peak between 2.2 and 1.6 Myr by comparing with the periods 3.2-2.2 and 2.2-1.6 Myr. Although we mainly develop our arguments about the 2.2-1.6 Myr event, we also provide information about the period preceding it as highlighted in lines 14-22 (p.5543): 'Prior to the event, between 3.2 and 2.2 Myr, export production was overall low while ïĄď15N values were relatively high and variable, indicating that nutrient supply was relatively weak, or at least much lower than during the high export production peak. Foraminiferal stable isotope and SST records from Mg/Ca suggest a deepening of the thermocline north and south of the equator between 3.2 and 2.2 Myr (Steph et al., 2009), implying a narrow equatorial cold tongue and a shift of the EF to the south of equator. The export production and isotope data at our study sites are consistent with low nutrient supply such as what might occur if they were beneath or to the north of the EF, under the nutrient-poor NECC's influence.' Moreover, the interpretation of our ïĄď15N records in line with paleoproductivity proxies is discussed in the manuscript for the entire period considered here and not restricted to 2.2-1.6 Myr. In addition, we included a new paragraph, as the reviewer suggests, describing the use of each proxies, the CaCO3 and why dilution or concentration effects are unlikely significant (line 140-158, p.5-6): 'TN and TOC represent the overall phytoplankton production, while C37 concentration reflects changes in alkenone producers, most probably Reticulofenestra species (Bolton et al., 2011). Changes in preservation, dilution, and concentration might affect the paleoproductivity signal traced by the different proxies. The mass accumulation rate (MAR) of sediment constituent is commonly applied to estimate past export productivity fluxes. However, although the age model at our EEP sites is well constrained, the use of MAR instead of content can be largely uncertain regarding the export productivity produced in the subsurface waters (François et al., 2004). In addition, the carbonate (CaCO3) content does not vary significantly since

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3.0 Myr (Mix et al., 2003), implying that changes in dilution or concentration of the other - more minor biogenic components by carbonate fluctuations - are not driving the fluctuations of the records. The exception may be during the high TOC/TN/C37 interval, where CaCO3 content decreases slightly (Mix et al., 2003). This probably represents a decrease in CaCO3 preservation due to high TOC delivery, but it was relatively minor compared to the high productivity-related concentrations peak centered between 2.2-1.6 Myr. Therefore, preservation effects did unlikely play a significant role on controlling the paleoproductivity signal. This is further supported by similar variations in export productivity reconstructed at all EEP sites (e.g. Dekens et al., 2007; Lawrence et al., 2006). In addition, a recent work based on paleoproductivity reconstructions in this region spanning the same time interval reported consistent variations between the C37 concentration and independent floral data (Bolton et al., 2011).'

Technical corrections Line 9 page 5537: "surpassing by a factor of almost ten that of the last deglaciation". Please add reference. Response: the reviewer is right to underline this point. The number 'ten' is rather abusive in the text in a way that it might be true for alkenone concentration at our EEP sites, but not for TN or TOC where it is closer to five. Also, depending on the records and studied EEP sites considered, there are several variations in this number. For making it more comprehensive and rigorous, we prefer to write 'surpassing largely that of the deglaciation' as shown by the data. The readers can easily identify it.

Line 11 page 5537: "to" a lesser extent Response: changed.

Line 15 page 5537: "Changes in circulation in the North Atlantic related to ice sheet expansion were also invoked to explain the spatial distribution of nutrients in the low latitudes regions, and its impact on EEP variability (Bolton et al., 2011)." In the cited paper, Bolton et al in fact suggest that oceanographic conditions at tropical sites are strongly linked to changes occurring in the Southern Ocean via upwelling and the circulation of sub Antarctic mode water, but that productivity at high-latitude northern hemisphere sites may be responding more directly to northern hemisphere ice-sheet

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growth. Response: we included the reference ‘Bolton et al., 2011’ in line 16 and deleted the sentence related to North Atlantic.

Line 10-15 page 5538: it is not clear if you are talking exclusively about the EEP or equatorial regions in general. Please clarify. Response: EEP added.

Line 24 page 5538 and line 1 page 5539: tuned “to” the LR04 stack Response: changed.

Line 11-13 page 5539: do the quoted precisions apply to both machines? Response: added.

Line 20 page 5539: same time “as” the Uk37 Response: changed.

Line 21 page: “0.05 units” - what units? Response: modified.

Line 2 page 5541: record not records Response: changed.

Section 5.2: In the introductory part of this section, it might be useful (for readers not versed in nitrogen isotope systematics and interpretation) to explicitly state “an increase in bulk sedimentary d15N is interpreted as indicating an increase in relative nutrient utilisation, either via an increase in N utilisation by phytoplankton and bacteria or a decrease in N supply to surface waters” or something similar. Response: sentence included.

Line 4 page 5543: the increased demand for nutrients “suggested” by the “high” export production Response: modified.

Line 10 page 5543: where the nutrients “are” sourced Response: changed.

Line 1 page 5544: the intensification of what? Response: ‘the EEP upwelling’ has been added.

Line 26 page 5545: over the last X(?) million years Response: 5.3 Myr added.

Figure 1 caption: provide references for the SST, chlorophyll and nitrate data on the

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maps. Response: reference ‘Levitus and Boyer, 1994’ added.

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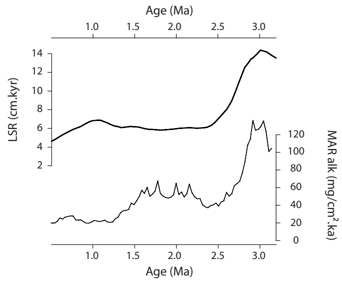

Figure 1. Smoother LSR and MAR alkenone concentration at the EEP Site 1239.

Fig. 1.