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# *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.

**G. Filippelli (Referee)**

gfilippe@iupui.edu

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The mystery of the early Pleistocene productivity burst (from 2.2-1.6 Ma) in the eastern equatorial Pacific (EEP) has spurred several attempts to determine its scope and drivers. The transience of the productivity burst indicates a temporary reorganization of water masses and related changes in nutrient import to the eastern equatorial Pacific as circulation stepped from a late Pliocene steady state to a later Pleistocene steady state. Several drivers and processes have been invoked to explain this transition state (e.g., Cortese et al, 2004; Lawrence et al., 2006; Bolton et al., 2011; Etourneau et al., 2012) but little integrated work on nutrient input, productivity, and upwelling in the EEP



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has been done.

This strong and very straightforward paper by Etourneau et al. examines several sites in the EEP using a water temperature/upwelling proxy (C37) coupled with a productivity proxy (total nitrogen) and a productivity+preformed nutrient proxy ($\delta$15N) to reveal that the productivity burst is substantial, is related to greater upwelling, and likely was sourced from polar water masses. Together these proxies indicate a transient phenomenon in the EEP marked by an expanded equatorial cold tongue with higher nitrate concentrations. This state eroded by 1.6 Ma, likely due to a reduction in nitrate export from the polar regions. This latter mechanism is intriguing, and has been suggested by Billups et al. (2013) to be the result of increased nutrient utilization in the Southern Ocean, maybe fueled by iron input (Martinez-Garcia et al., 2011). Thus, the Southern Ocean (and perhaps north Pacific) may have become nutrient dumps over the last 1.6 my, limiting the supply to nutrients to the EEP and thus modulating equatorial productivity.

The consistent picture provided by the upwelling and productivity proxies here is consistent with an “internal only” driver of nutrient availability during this time. In other words, these results do not require an external source of increased nutrient supply, like continental weathering, to fuel the EEP productivity event. It is a simple swapping of nutrients between polar and equatorial regions via changing circulation patterns. Interestingly, though, the results do not rule out external factors, and indeed do note that iron supply in the high latitudes might have helped fix nutrients there and thus limited the concentration of the supply to the EEP. But in addition to iron, the most critical nutrient for long-term productivity in the oceans, phosphorus (Tyrrell, 1999), is not discussed.

Unlike nitrogen, which can be supplied either by continental input or by fixation of dissolved N2, phosphorus comes to the ocean almost exclusively from continental weathering. Phosphorus can be recycled from sinking particles in oxygen minimum zones (especially the oxide-bound fraction) and from remineralization upon organic matter degradation at the seafloor, but ultimately it is in limited supply and tends to serve as



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the ultimate control on total net productivity. Because the residence time of phosphorus is relatively long (∼20-30 kyr; Colman and Holland, 2000), it responds from slowly than those of nitrogen or indeed iron, and plays an important background role in setting the productivity baseline (Filippelli et al., 2007) and indeed in setting the ecosystem type (Flores et al., 2012). One implication of this with respect to the end of the EEP productivity burst is that perhaps it was not nitrogen that ran out, but rather phosphorus. This conceptually makes sense given the potential for nitrogen fixation to have continued to provide nitrate to the EEP, but there is not yet any sedimentary evidence for a phosphorus limitation. But the duration of the productivity increase (about 600 kyr) could be consistent with a continual draining of the marine phosphorus pool, resulting in a lower concentration of phosphorus upwelled water in the EEP and thus lower net production. Intriguingly, this might have caused very high N:P ratios in the upwelled water, altering ecosystem structure. All suppositions aside, the phosphorus story might be an important but heretofore overlooked piece of the nutrient puzzle here.

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