MATTERS ARISING
https://doi.org/10.1038/s41561-019-0305-y
nature geoscience

Reply to: No evidence for equatorial Pacific dust fertilization

F. Marcantonio[1]*, M. R. Loveley[2], M. W. Schmidt[3] and J. E. Hertzberg[3]

REPLYING TO A. W. Jacobel et al. *Nature Geoscience* https://doi.org/10.1038/s41561-019-0304-z (2019)

We disagree with the arguments put forth by Jacobel et al.[1] and stand by our original interpretations[2]. Jacobel et al.[1] assert that no evidence of Fe fertilization by dust is provided by Loveley et al.[2] and claim the same for their dataset from nearby Ocean Drilling Program (ODP) Site 1240. However, we interpret their dataset differently: there is a moderate, statistically strong positive correlation between the excess Ba (xsBa) and ^{232}Th fluxes (coefficient of correlation, $r=+0.49$, $P<0.01$; fig. 1a in ref. [1]). The relationship between their ^{232}Th and Fe fluxes is even stronger ($r=+0.62$, $P<0.01$; Fig. 1b in ref. [1]), indicating a significant influence of dust on Fe availability.

Fluxes of xsBa scale nonlinearly with dust flux at site MV1014-02-17JC. We stated that, and noted a clear relationship between xsBa and dust "during or near Heinrich Stadials (HS) 1, 2, 5, 6 and 7"[2]. For HS6 and 7 there are statistically significant positive correlations between xsBa and dust fluxes ($r=+0.47$, $P<0.05$ and $r=+0.96$, $P<0.01$, respectively). For HS1, 2 and 5, xsBa is likely affected by bottom-water hypoxia, defined by authigenic U values that are the highest in the entire record (>10 ppm)[2]. The low-O_2 bottom waters probably released Ba[3], which diffused downwards slightly and re-precipitated, causing the xsBa flux to lead the dust flux signal by only ~1 kyr.

We see no evidence in Jacobel et al.[1] in support of their claim that upwelling of equatorial undercurrent waters provides all of the Fe and is the sole cause of fertilization in the easternmost eastern equatorial Pacific (EEP). During past cold events, similar to boreal winter conditions today, a southward-shifted intertropical convergence zone probably reduced equatorial upwelling[4]. Regardless, Fe concentrations in the eastward-flowing equatorial undercurrent, sourced from continental inputs in the western Pacific, are nearly zero by 110° W due to scavenging and the short residence time of Fe (0.8–1.0 nM at 140° W to ≤0.09 nM at 110° W)[5]. Even farther east, the Galapagos Islands obstruct, deflect and weaken the equatorial undercurrent[6], making the role it plays in supplying Fe to our site at 86° W even less likely. It is apparent that our site would be more sensitive to dust fertilization due to continental proximity, which leads to dust fluxes that are about 5–10 times greater than those at all 11 locations considered by Jacobel and colleagues[1]. In fact, east of the Galapagos Islands[2,7–12], changes in aeolian delivery and its role in export production and the global CO_2 cycle cannot be ruled out. We therefore find the assertions[1] that there is unquestionably no dust fertilization at our site or theirs to be unwarranted.

The EEP is the greatest oceanic source of CO_2 to the atmosphere today[13], yet an abundance of data show that the easternmost EEP may have been a net sink of CO_2 at times during the last deglacial and glacial periods[7,9–12]. The argument[1] against net changes in biological pump efficiency and atmospheric p_{CO_2} drawdown relies on nutrients sourced from equatorial upwelling, resulting in surface waters with elevated CO_2 concentrations. This assumption fails to consider that Fe fertilization from dust can increase the efficiency of the biological pump and carbon sequestration in a high nutrient–low chlorophyll region, even with no net changes in upwelling.

Received: 21 August 2018; Accepted: 7 January 2019;
Published online: 27 February 2019

References

1. Jacobel, A. W. et al. No evidence for equatorial Pacific dust fertilization. *Nat. Geosci.* https://doi.org/10.1038/s41561-019-0304-z (2018).
2. Loveley, M. R. et al. Millennial-scale iron fertilization of the eastern equatorial Pacific over the past 100,000 years. *Nat. Geosci.* **10**, 760–764 (2017).
3. McManus, J. et al. Geochemistry of barium in marine sediments: implications for its use as a paleoproxy. *Geochim. Cosmochim. Acta* **62**, 3453–3473 (1998).
4. Fiedler, P. C. & Talley, L. D. Hydrography in the eastern tropical Pacific: a review. *Progr. Oceanogr.* **69**, 143–180 (2006).
5. Kaupp, L. J. et al. The distribution of dissolved Fe and Al in the upper waters of the eastern equatorial Pacific. *Deep Sea Res. Part II* **58**, 296–310 (2011).
6. Lukas, R. The termination of the equatorial undercurrent in the eastern Pacific. *Progr. Oceanogr.* **16**, 63–90 (1986).
7. de la Fuente, M. et al. The evolution of deep ocean chemistry and respired carbon in the eastern equatorial Pacific over the last deglaciation. *Paleoceanography* **32**, 1371–1385 (2017).
8. Costa, K. M. et al. Productivity patterns in the equatorial Pacific over the last 30,000 years. *Glob. Biogeochem. Cycles* **31**, 850–865 (2017).
9. Martínez-Botí, M. A. et al. Boron isotope evidence for oceanic carbon dioxide leakage during the last deglaciation. *Nature* **518**, 219–222 (2015).
10. Doss, W. & Marchitto, T. M. Glacial deep ocean sequestration of CO_2 driven by the eastern equatorial Pacific biologic pump. *Earth Planet. Sci. Lett.* **377–378**, 43–54 (2013).
11. Robinson, R. S., Martinez, P., Pena, L. D. & Cacho, I. Nitrogen isotopic evidence for deglacial changes in nutrient supply in the eastern equatorial Pacific. *Paleoceanography* **24**, PA4213 (2009).
12. Pichevin, L. E. et al. Enhanced carbon pump inferred from relaxation of nutrient limitation in the glacial ocean. *Nature* **459**, 1114–1117 (2009).
13. Takahashi, T. et al. Global sea-air CO_2 flux based on climatological surface ocean pCO_2, and seasonal biological and temperature effects. *Deep Sea Res. Part II* **49**, 1601–1622 (2002).

Author contributions

F.M., M.R.L., M.W.S. and J.E.H. each contributed to the discussion, writing and editing of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Reprints and permissions information is available at www.nature.com/reprints.

Correspondence and requests for materials should be addressed to F.M.

Publisher's note: Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

[1]Department of Geology and Geophysics, Texas A&M University, College Station, TX, USA. [2]Zedi, Midland, TX, USA. [3]Department of Ocean, Earth, and Atmospheric Sciences, Old Dominion University, Norfolk, VA, USA. *e-mail: marcantonio@geos.tamu.edu