Not So Permanent El Niño

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Science **344**, 52 (2014);
DOI: 10.1126/science.1252246

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crust when compared with cooler mantle (see the figure). Hotter mantle also produces compositionally different lavas because it melts more, and seismic waves slow down when traversing hotter mantle. The seismic properties of the mantle beneath the ridge, the composition of the erupted lava, and the morphology of the ridge axis thus provide three independent sensors of mantle temperature. By compiling global-scale data sets, enabled through modern geoinformatics efforts (*4*, *5*), Dalton *et al*. show that the parameters of axial depth, lava composition, and seismic wave velocity covary globally, as expected from variations in mantle temperature.

Yet, temperature is not the only factor that controls the physical and chemical attributes of mid-ocean ridges. Other recent assessments of global-scale data sets have challenged a primary role for temperature variations (*6*). By taking different approaches to constraining axial depth and correcting lava compositions for the effects of crystallization within the crust, such studies argue that variations in mantle composition are the main control on axial depth and lava chemistry, with minor temperature variations (<50°C) (*6*).

By including the mantle seismic properties in their analysis, Dalton *et al*. suggest that temperature is indeed the primary factor. Higher mantle temperatures are expected to produce shallower ridge axes, lavas with lower sodium concentrations, and lower seismic wave speeds. How mantle composition relates to axial depth, lava composition, and seismic velocity, on the other hand, depends on how it is defined. For example, in (*6*) and (*1*), the mantle composition may vary globally as a function of how much it has melted previously, which influences its density and the composition and volume of magma it produces when melted but does not appreciably influence the speed of seismic waves that travel through it.

A key role, however, remains for mantle composition to determine the physical and chemical attributes of global mid-ocean ridges, because we know Earth's upper mantle is chemically heterogeneous. Compositionally distinct crustal materials from Earth's near-surface environment, such as marine sediments and oceanic crust, have been returned to the mantle through the subduction of tectonic plates at ocean trenches, enriching the mantle in elements such as volatiles (for example, H_2O and CO_2) that may influence mantle properties. The water content of the mantle affects the seismic velocities (*7*), as well as affecting the amount and composition of the crust produced by melting (*8*). A wetter mantle yields lower seismic velocities, thicker crust, and shallower ridge axes, similar to the effects of higher mantle temperature, but lava composition would define trends orthogonal to those found by Dalton *et al*. Similarly, trace quantities of carbon in the mantle could drive small amounts of melting at great depth beneath mid-ocean ridges (*9*), which may also influence seismic velocities and lava composition.

To what extent do water, carbon, and other compositional factors vary in Earth's mantle, and over what length scales? How are these variations expressed in the physical and chemical structure of modern mid-ocean ridges and the oceanic crust? Two potential paths forward involve global and local scale studies of the ridge system. Progress in constraining global-scale variations of H_2O and CO_2 in mid-ocean ridge lavas, and their mantle sources, lags behind our understanding of other elements. As global data sets and models of volatile element distribution develop, we may more fully resolve the competing effects of temperature and composition on global-scale geophysical and geochemical characteristics of spreading ridges. Smaller length scales of compositional heterogeneity in the mantle may also be poorly resolved by globally averaged data sets (*10*), requiring focused, local studies of the ridge system to access smaller-scale features.

References

1. C. A. Dalton, C. H. Langmuir, A. Gale, *Science* **344**, 80 (2014).
2. A. Gale, C. A. Dalton, C. H. Langmuir, Y. Su, J.-G. Schilling, *Geochem. Geophys. Geosyst.* **14**, 489 (2013).
3. C. H. Langmuir, E. M. Klein, T. Plank, *Geophys. Monogr.* **71**, 183 (1992).
4. K. Lehnert, Y. Su, C. H. Langmuir, B. Sarbas, U. Nohl, *Geochem. Geophys. Geosyst.* **1**, 1 (2000).
5. W. B. F. Ryan *et al*., *Geochem. Geophys. Geosyst.* **10**, Q03014 (2009).
6. Y. Niu, M. J. O'Hara, *J. Pet.* **49**, 633 (2008).
7. S.-i. Karato, *Geophys. Monogr.* **138**, 135 (2003).
8. P. D. Asimow, C. H. Langmuir, *Nature* **421**, 815 (2003).
9. R. Dasgupta, M. M. Hirschmann, *Earth Planet. Sci. Lett.* **298**, 1 (2010).
10. L. Stixrude, C. Lithgow-Bertelloni, *Annu. Rev. Earth Planet. Sci.* **40**, 569 (2012).

10.1126/science.1252089

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Not So Permanent El Niño

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Paleoclimate data point to a warm tropical ocean with a clear east-west temperature gradient during the warm climates of the Pliocene and Miocene.

Knowledge of the behavior of the tropical oceans under different climate conditions is important for understanding not only past climate change but also present and future global warming, especially given the recent finding that the cool state of the equatorial Pacific might be the cause of the current global warming hiatus (*1*). On page 84 of this issue, Zhang *et al*. evaluate the long-term evolution of tropical Pacific sea surface temperatures (SSTs) since 12 million years ago (*2*). They conclude that the equatorial Pacific was warmer during the Pliocene (5.3 to 2.6 million years ago) and late Miocene (12.0 to 5.3 million years ago) than it is today and that the temperature difference between the eastern and western tropical Pacific that is a fundamental characteristic of today's ocean was present (although somewhat smaller than it is today) during these warmer time intervals.

This view of the past tropical Pacific is strikingly different from the picture that has dominated paleoclimate thinking since 2005, when Wara *et al*. (*3*) argued that the tropical Pacific during the Pliocene was very different from that of today. In the present climate, the tropical Pacific is dominated by a distinct zonal gradient, with cool temperatures in the east and warm temperatures in the west (see the figure, panel A). Wara *et al*. reported Mg/Ca data showing that this gradient was nearly absent during the warmer climate of the Pliocene (see the figure, panel B). Because the equatorial zonal gradient slackens during El Niño events, the researchers called the Pliocene configuration a "permanent El Niño–like condition."

Since then, scientists have sought to understand the cause of the change, and in particular the observation that the Pliocene warm pool was no warmer than in preindustrial times, despite inferred higher atmospheric carbon dioxide concentrations in the Pliocene (*4*). Yet the warm pool is known

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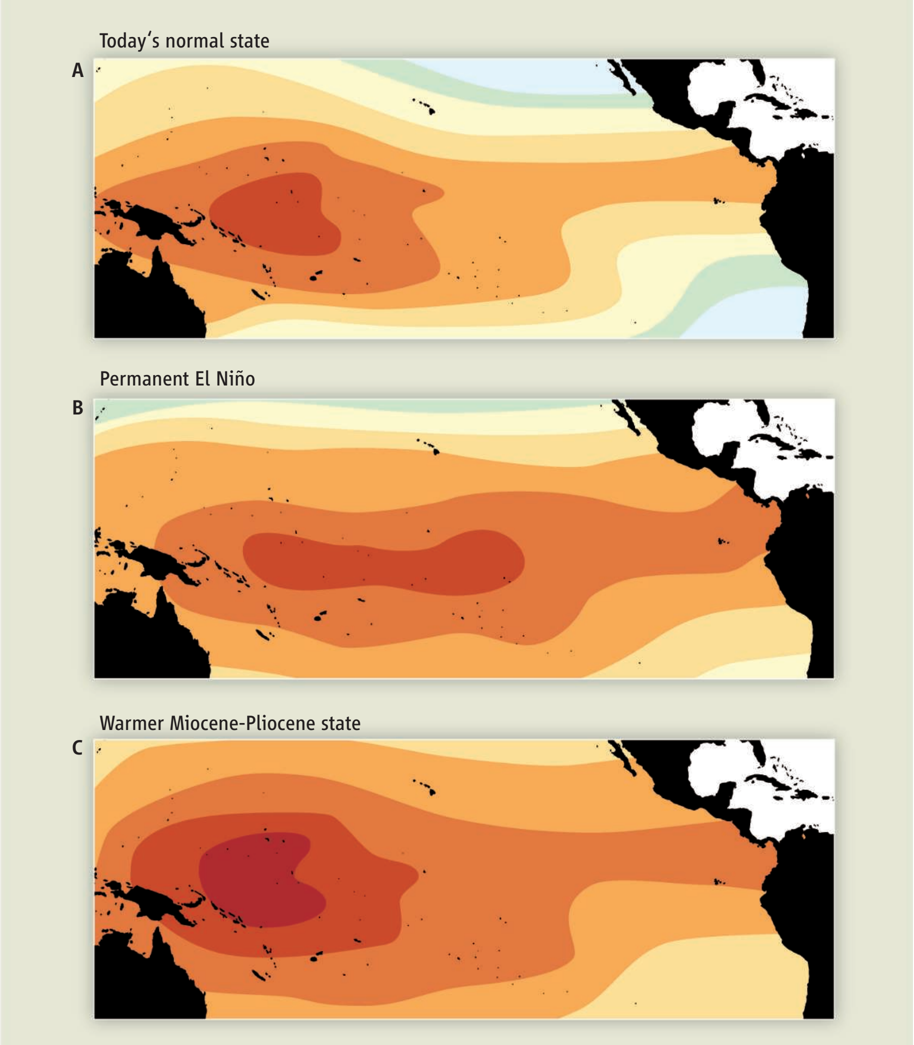

States of the Tropical Pacific. (**A**) The normal state for today's tropical Pacific. During El Niño events, the EEP warms by up to 5°C, while the WEP cools slightly; during La Niña events, the EEP cools by up to 3°C, while the WEP warms slightly. (**B**) Permanent El Niño–like state previously inferred for the Miocene-Pliocene (*4*), with a much warmer EEP and a similar or slightly cooler WEP. In this scenario, the zonal temperature gradient nearly vanishes. (**C**) In the warmer Miocene-Pliocene state inferred by Zhang *et al.*, both the EEP and WEP are warmer than they are today, as expected for the higher atmospheric CO_2 concentrations in the Miocene-Pliocene. The zonal gradient is only slightly smaller than in today's normal state.

to be sensitive to radiative forcing both in past (*5*) and modern climates (*6*), and therefore should warm with higher atmospheric greenhouse gas abundances. Fedorov *et al.* (*4*) have proposed some novel dynamical mechanisms to account for the lack of higher SSTs in the warm pool, but recent simulations show both warming of the warm pool and a tropical Pacific zonal gradient in the Pliocene (*7*). Overall, it is difficult to reconcile unchanged Pacific warm pool SSTs with higher atmospheric CO_2, smaller ice sheets, and much warmer conditions in the high-latitude Arctic (*8*).

Zhang *et al.*'s data may resolve this quandary. The authors use a relatively new paleotemperature proxy, TEX_{86}, which can record SSTs above 28°C, the upper limit for the widely used organic geochemical proxy $U_{37}^{K'}$. That limit is critical to studies of the Pacific warm pool, where modern SSTs exceed 28°C. The TEX_{86} data record warmer SSTs than exist today in both the eastern equatorial Pacific (EEP) and western equatorial Pacific (WEP) during the Pliocene and Miocene (see the figure, panel C). Averaging all available TEX_{86} and $U_{37}^{K'}$ proxy SST data suggests a progressive cooling of both the WEP and EEP since the Miocene, with intensified cooling after 4 million years ago. The east-west gradient never approached zero, as implied for a permanent El Niño–like state.

How can we reconcile these disparate views? As in many problems in paleoclimate, the differences come down to the strengths and weaknesses of the various proxies. Wara *et al.* (*3*) based their inferences on magnesium-to-calcium ratio (Mg/Ca), a proxy that is recorded in foraminifera shells and is particularly good at recording surface conditions. But secondary factors influence shell Mg/Ca, and these influences, which include changes in seawater composition and variable shell preservation, are amplified on longer time scales (*9*). For TEX_{86}, a compound synthesized by marine archaea, there are large uncertainties associated with where in the water column the compounds are synthesized and which calibration is best (*10*). The $U_{37}^{K'}$ proxy, synthesized by a few species of haptophyte algae, is far better characterized; the observation from this proxy that all warm pool samples of Miocene age and older formed at an SST of ≥28°C bolsters the inferences from TEX_{86} (*2*). A full resolution of these different views, however, cannot be achieved without future research into the efficacy of the proxies on Miocene and Pliocene time scales.

If the view of the past tropical Pacific that emerges from Zhang *et al.*'s study proves correct, it has strong implications for a number of emerging challenges in climate science. It becomes far less likely that future global warming might lead to a permanent El Niño–like state, especially given that simulations of future global warming do not show such a response (*11*). Furthermore, the TEX_{86} data support previous evidence that the warm pool responds strongly to radiative forcing (*5*, *6*). Finally, Zhang *et al.*'s data support theoretical and modeling studies showing that there are no regulating mechanisms limiting tropical SSTs from increasing above 30°C in response to higher greenhouse gases, both in the past and the future (*12*).

References and Notes

1. Y. Kosaka, S.-P. Xie, *Nature* **501**, 403 (2013).
2. Y. G. Zhang, M. Pagani, Z. Liu, *Science* **344**, 84 (2014).
3. M. W. Wara, A. C. Ravelo, M. L. Delaney, *Science* **309**, 758 (2005).
4. A. V. Fedorov *et al.*, *Nature* **496**, 43 (2013).
5. K. Tachikawa *et al.*, *Quat. Sci. Rev.* **86**, 24 (2014).
6. H. Tokinaga, S.-P. Xie, C. Deser, Y. Kosaka, Y. M. Okumura, *Nature* **491**, 439 (2012).
7. D. J. Hill *et al.*, *Clim. Past* **10**, 79 (2014).
8. A. P. Ballantyne *et al.*, *Geology* **38**, 603 (2010).
9. M. Medina-Elizalde, D. W. Lea, *Paleoceanography* **25**, PA2208 (2010).
10. J. E. Tierney, M. P. Tingley, *Geochim. Cosmochim. Acta* **127**, 83 (2014).
11. P. N. DiNezio *et al.*, *J. Clim.* **22**, 4873 (2009).
12. I. N. Williams, R. T. Pierrehumbert, M. Huber, *Geophys. Res. Lett.* **36**, L21805 (2009).

Acknowledgments I thank P. DiNezio for discussion and NSF OCE-1260696 for support.

10.1126/science.1252246