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The Western Pacific Warm Pool: A Probe of Global Sea Level Change and Indonesian Seaway Closure During the Middle to Late Miocene

Nathan, Stephen A., Department of Geosciences, University of Massachusetts, Amherst, MA; R. Mark Leckie, Department of Geosciences, University of Massachusetts, Amherst, MA; Brooke Olson, Department of Geosciences, University of Massachusetts, Amherst, MA; Robert M. DeConto, Department of Geosciences, University of Massachusetts, Amherst, MA.

Major tectonic events suspected to be at the core of the long-term late Cenozoic climatic cooling have included the uplift of the Himalaya/Tibetan Plateau (e.g., Kutzbach et al., 1989), and the successive closure of tropical oceanic gateways, including the Indonesian Seaway (IS)(Figure 1; e.g., Kennett et al., 1985; Lawver et al., 1992; Gasperi and Kennett, 1993). These two "events" are responsible for the development of strong monsoonal climate over central Africa and Asia, and the development of the equatorial Pacific current system and strengthening of the wind-driven circulation of the Pacific, respectively. Yet, the timing of tectonically driven changes in the ocean-climate system is poorly constrained, particularly the effective closure of the IS, which has estimates ranging between ~17 Ma and 3-4 Ma (e.g., Kennett, 1985; Gasperi and Kennett, 1993; Nishimura and Suparka, 1997; Cane and Molnar, 2001). The development of the Western Pacific Warm Pool (WPWP) was one consequence of the gradual constriction of the IS.

We contend that the development of the WPWP was closely linked with the restriction of surface water flow through the IS. When did this oceanographic feature become established and did it influence the East Asian monsoon? We present preliminary results of an investigation into the development of the WPWP as the IS narrowed during middle to late Miocene time (Figs. 2-3).

Methods

This study utilizes planktic foraminiferal analyses at tectonic scale resolution for the purpose of reconstructing the upper water column structure and evaluating the nature of paleoproductivity across the western tropical Pacific. Initially, the stable isotopic compositions of multiple discrete size fractions of multiple species of planktic foraminifera from four Miocene time slices (~7, 9, 11, and 13 Ma) and a surface box core (0 Ma) sample from each of three ODP sites were analyzed (Nathan, in progress). These analyses allowed each taxon to be assigned to a specific water column layer (e.g., mixed layer, thermocline, or subthermocline).

With species depth habitats established, two independent and complementary proxies were used to determine upper water column characteristics. These proxies were: 1) planktic foraminiferal census data and 2) multi-species stable isotopic data. These analyses provided insights into the thickness of the mixed layer and thermocline, as well as the nature of seasonal productivity and biogeographic mixing of assemblages, and in turn, regional oceanography (e.g., Chaisson, 1995; Chaisson and Ravelo, 2000). Through the interval of ~13-6 Ma we analyzed (at ~100 kyr resolution) one mixed-layer species, one thermocline species, and one species from the base of the photic zone, as well as one epifaunal benthic taxon from each sample. The three planktic species provide coverage for a range of isotopic gradients in the upper water column of the middle to late Miocene tropical ocean (e.g., Gasperi and Kennett, 1993; Nathan, in progress). Spatially, these techniques were applied across three ODP sites from the South China Sea (SCS) and Ontong Java Plateau (OJP): southern SCS Site 1143 (9º21´N, 113º17´E, depth 2783 m), northern SCS Site 1146 (19º27´N, 116º16´E, depth 2103 m), and OJP Site 806 (0º19.1´N, 159º21.7´E, depth 2520 m).

Preliminary Results

At Site 1146 the modern assemblage, which is influenced by the East Asian monsoon, is 42% surface and 58% thermocline dwellers. At OJP, surface dwellers dominate (81%) over the thermocline dwellers (17%), reflecting the thicker mixed layer and deeper thermocline observed in the WPWP. At ~7 Ma the population assemblages are reversed between the two sites while the isotopic analyses of OJP show a >1.3‰ $\delta^{18}O$ enrichment compared to modern values. Both the ~7 Ma population structure and the isotopic data show that the WPWP was absent at OJP. At ~11Ma, the assemblages at both sites are nearly identical to the modern OJP, implying the presence of a "proto-WPWP" (Nathan et al. 2001; Figs. 2 and 3). These data suggest that the Miocene closure history of the IS was punctuated by times of variable throughflow.

Relevance of Study

We hypothesize that Indonesian Throughflow (ITF) was modulated by changing sea-level (Nathan et al., 2001; Olson et al., 2001). For example, a sea-level fall of nearly 86 m (+/-30 m) at the end of the middle Miocene (Isern et al., 2001) may correspond with the major eustatic sea-level fall on the Haq et al. sea-level curve (1988) and the Mi5 Miocene deep-sea isotope event (Miller and Mountain, 1996; Billups and Schrag, 2002), which in turn decreased ITF and established a proto-WPWP. The development of the proto-WPWP (~11-9 Ma) also coincides with a marked decrease in carbonate mass accumulation rates throughout the tropical ocean (i.e., the "carbonate crash"; e.g., Lyle et al., 1995; Roth et al., 2000). We further speculate that the subsequent sea level rise during the late Miocene once again increased ITF and reduced the WPWP (~8-5 Ma). This major change in tropical surface circulation may have modulated climate by diminishing an important latent heat source to Southeast Asia as well as strengthening western boundary currents in the Pacific. In addition, carbonate productivity was stimulated across the tropical Indo-Pacific as evidenced by increased carbonate mass accumulation rates from ~8-5 Ma (i.e., the "biogenic bloom"; Peterson et al, 1992; Farrell et al, 1995).

References cited:

Billups, K., and Schrag, D.P., 2002. Paleotemperatures and ice volume of the past 27 Myr revisited with paired Mg/Ca and 18O/16O measurements on benthic foraminifera. *Paleoceanography,* 17:1, 3-1 - 3-11.

Cane, M.A., and Molnar, P., 2001. Closing of the Indonesian seaway as a precursor to east African aridification around 3-4 million years ago. *Nature*, 411:157-162.

Chaisson, W., 1995. Planktonic foraminiferal assemblages and paleoceanographic change in the trans-tropical Pacific ocean: A comparison of west (Leg 130) and east (Leg 138), latest Miocene to Pleistocene. *In* Pisias, N.G., Mayer, L.A., Janecek, T.R., Palmer-Julson, A., and van Andel, T.H. (Eds.), *Proceedings of the Ocean Drilling Program, Sci. Results*, 138: College Station, TX (Ocean Drilling Prog.), 555-597.

Chaisson, W.P., and Ravelo, A.C., 2000. Pliocene development of the east-west hydrographic gradient in the equatorial Pacific. *Paleoceanography,* 10, 5: 497-505.

Farrell, J.W., Raffi, I., Janecek, T.R., Murray, D.W., Levitan, M., Dadey, K.A., Emeis, K.-C., Lyle, M., Flores, J.-A., and Hovan, S., 1995. Late Neogene sedimentation patterns in the eastern equatorial Pacific Ocean. *In* Pisias, N.G., Mayer, L.A., Janecek, T.R., Palmer-Julson, A., and van Andel, T.H. (Eds.), *Procs of the Ocean Drilling Program, Sci. Results*, 138: College Station, TX (Ocean Drilling Prog.), 717-753.

Gasperi, J.T., and Kennett, J.P., 1993. Vertical thermal structure evolution of Miocene surface waters: Western equatorial Pacific DSDP Site 289, *Marine Micropaleontology,* 22: 235 – 254.

Haq, B.U., Hardenbol, J., and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and cycles of sea level change, *In* Wilgus, C.K., Hastings, B.S., Posamentier, H., van Wagoner, J., Ross, C.A., and Kendall, C.G.S., Eds., *Sea Level Changes: An Integrated Approach*. SEPM Special Pub. 42:71-108.

Isern, A. R., Anselmetti, F., Blum, P., 2001. Sea-level Magnitudes Recorded by Miocene Continental Margin Sequences on the Marion Plateau, Northeast Australia: ODP Leg 194. [Online]. AGU Meetings Database (Spring 2001): <http://www.agu.org/meetings/waissm01.html>. [Cited 2001/08/15].

Kennett, J.P., Keller, G., and Srinivasan, M., 1985. Miocene planktonic foraminiferal biogeography and paleoceanographic development of the Indo-Pacific region. *In* Kennett, J.P., (Ed.), *The Miocene Ocean: Paleoceanography and Biogeography.* Memoir 163, Geological Society of America, 197 – 236.

Kutzbach, J.E., Guetter, P. J., and Ruddiman, W.F., and Prell, W.L., 1989. The sensitivity of climate to late Cenozoic uplift in southeast Asia and the American southwest: numerical experiments. *Jouranl of Geophys. Res.*, 94:18393-18407.

Lawver, L.A., Gahagan, L.M., Coffin, M.F., 1992. The development of paleoseaways around Antarctica. *In*: Kennett, J.P., and Warnke, D.A., (Eds.) *The Antarctic paleoenvironment: A perspective on global change*, Am. Geophys. Union, Ant. Res. Ser. 56, 7-30.

Lyle, M., Dadey, K.A., and Farrell, J.W., 1995. The late Miocene (11-8 Ma) eastern Pacific carbonate crash: evidence for reorganization of deep-water circulation by the closure of the Panama gateway. *In* Pisias, N.G., Mayer, L.A., Janecek, T.R., Palmer-Julson, A., and van Andel, T.H. (Eds.), *Proceedings of the Ocean Drilling Prog., Scientific Results*, 138: College Station, TX (Ocean Drilling Prog.), 821-838.

Miller, K.G., and Mountain, G.S., 1996. Drilling and dating New Jersey Oligocene-Miocene sequences: Ice volume, global sea level, and Exxon records. *Science,* 271:1092-1095.

Nathan, S.A., Leckie, R.M., DeConto, R.M., and Flower, B.P., 2001. Development of the Western Pacific Warm Pool during the late Miocene: linkages between tectonic gateway closure and sea level. AGU Spring Meeting, EOS, Transactions, 82(20):S224.

Nishimura, S. and Suparka, S., 1997. Tectonic approach to the Neogene evolution of Pacific – Indian Ocean seaways. *Tectonophysics*, 281: 1 – 16.

Olson, B.E., DeConto, R.M., and Leckie, R.M., 2001. Late middle Miocene to late Miocene paleoceanography of the western Coral Sea: Foraminiferal population and isotopic analysis of ODP Leg 194 Hole 1195B. GSA Abstracts with Programs, 33(6):A20.

Peterson, L.C., Murray, D.W., Ehrmann, W.U., and Hempel, P., 1992. Cenozoic carbonate accumulation and compensation depth changes in the Indian Ocean. *Synthesis of Results from Scientific Drilling in the Indian Ocean*, AGU Geophyscial Monograph 70: 311-333.

Roth, J., Droxler, A., and Kameo, K., 2000. The Caribbean carbonate crash at the middle to late Miocene transition: linkages to the establishment of the modern global ocean conveyor. *In* Leckie, R.M., Sigurdsson, H., Acton, G.D., and Draper, G., Pisias, (Eds.), *Proceedings of the Ocean Drilling Program, Scientific Results*, 165: College Station, TX (Ocean Drilling Program), 249-274.

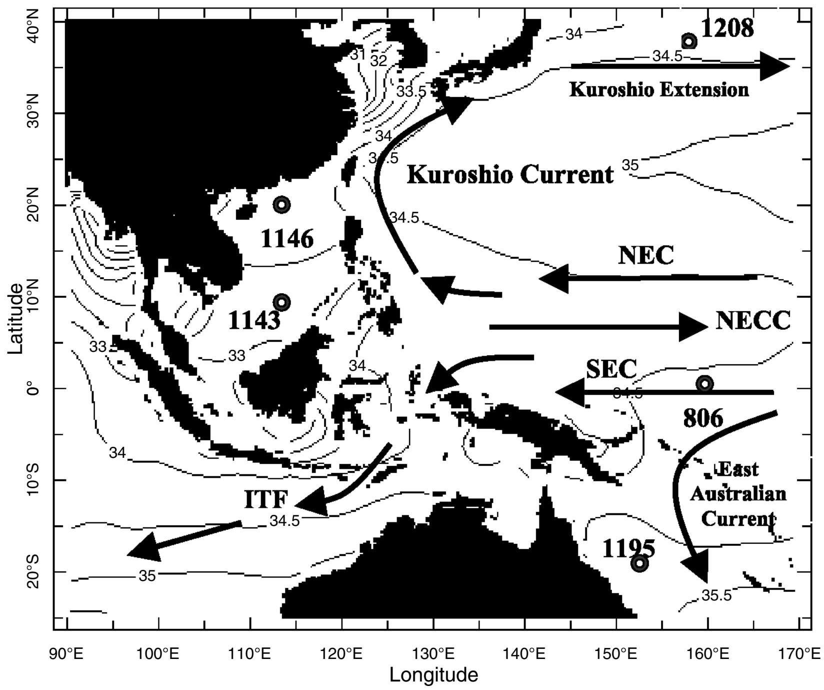

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Figure 1. Location of study sites for this study (ODP Site 806, Ontong Java Plateau; ODP Sites 1143 & 1146, South China Sea) and parallel studies (ODP Sites 1195, Marion Plateau; 1208, Shatsky Rise). Site 806 is located in the core of the modern Western Pacific Warm Pool (WPWP) while Sites 1143 and 1195 are within the seasonal limit of the WPWP. Sites 1143 & 1146 are within the seasonal range of the East Asian Monsoon. Note: Site 1143 overlaps with both the WPWP and the East Asian Monsoon. Sites 1195 and 1208 both serve to monitor the downstream effects of: 1) the constriction of the Indonesian Seaway and changes in sea level; 2) the development of the WPWP; and 3) intensification of western boundary currents.

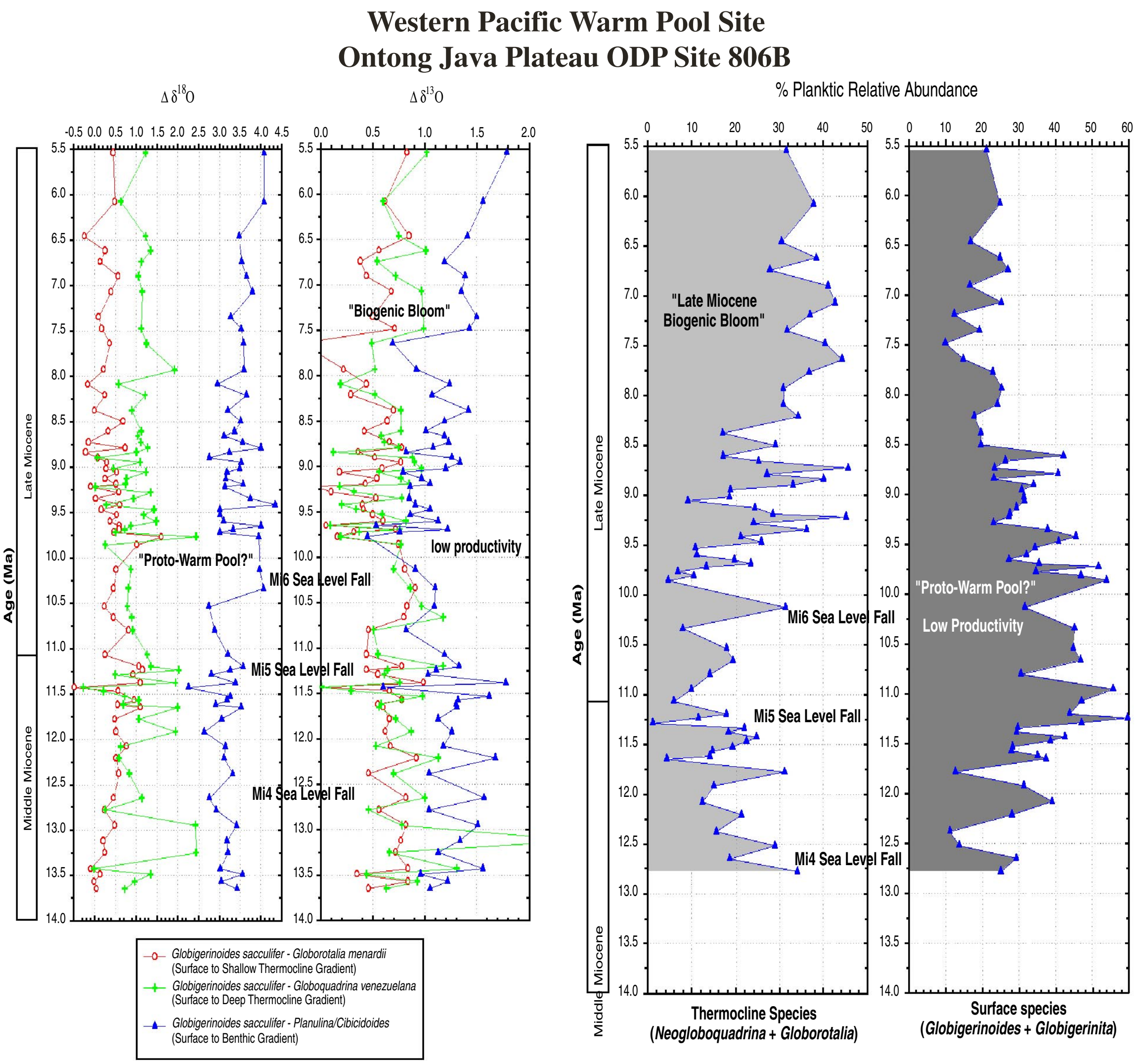

Figure 2. Left, Preliminary data from ODP Site 806 (Nathan in prep) on Ontong Java Plateau. Noteworthy is the decrease in $\Delta\delta^{13}C$ (surface to benthic gradient) from ~11.25 Ma to ~9.2 Ma. This period of low ^{13}C gradients implies low productivity where surface species dominate over thermocline species (see right half of this figure and Fig 3). It is during this interval that a proto-WPWP may have existed (having a thick mixed layer and a deep thermocline). The increasing $\Delta\delta^{13}C$ during the interval of ~9.2 Ma - 5.5 Ma implies increasing productivity. This is borne out by the relative increase in the abundance of thermocline species and corresponding decrease in surface species (see right half of this figure and Figure 3). Mi4, Mi5 and Mi6 indicate the oxygen isotope enrichments of Miller et al. (1996). **Right,** Planktic foraminiferal population analyses for a continuous record from the Ontong Java Plateau, Site 806 (Nathan in prep.). In the ancient record the abundances of surface species (Globigerinoides and Globigerinita) vary considerably over time (right half of right diagram). Specifically, the sum of these two genera at ~**7 Ma** is ~10-15%, implying the **lack of a WPWP** and greater productivity and/or seasonality as indicates by the abundance of thermocline dwellers (~40%) and by the increasing $\delta^{13}C$ planktic-benthic gradients. At ~**11 Ma**, a "**proto-WPWP**" may have existed as indicted by the dominance of these same two genera (~40-60%). Warm pool-like conditions may have also characterized parts of the South China Sea in the late Miocene prior to the intensification of the East Asian Monsoon.

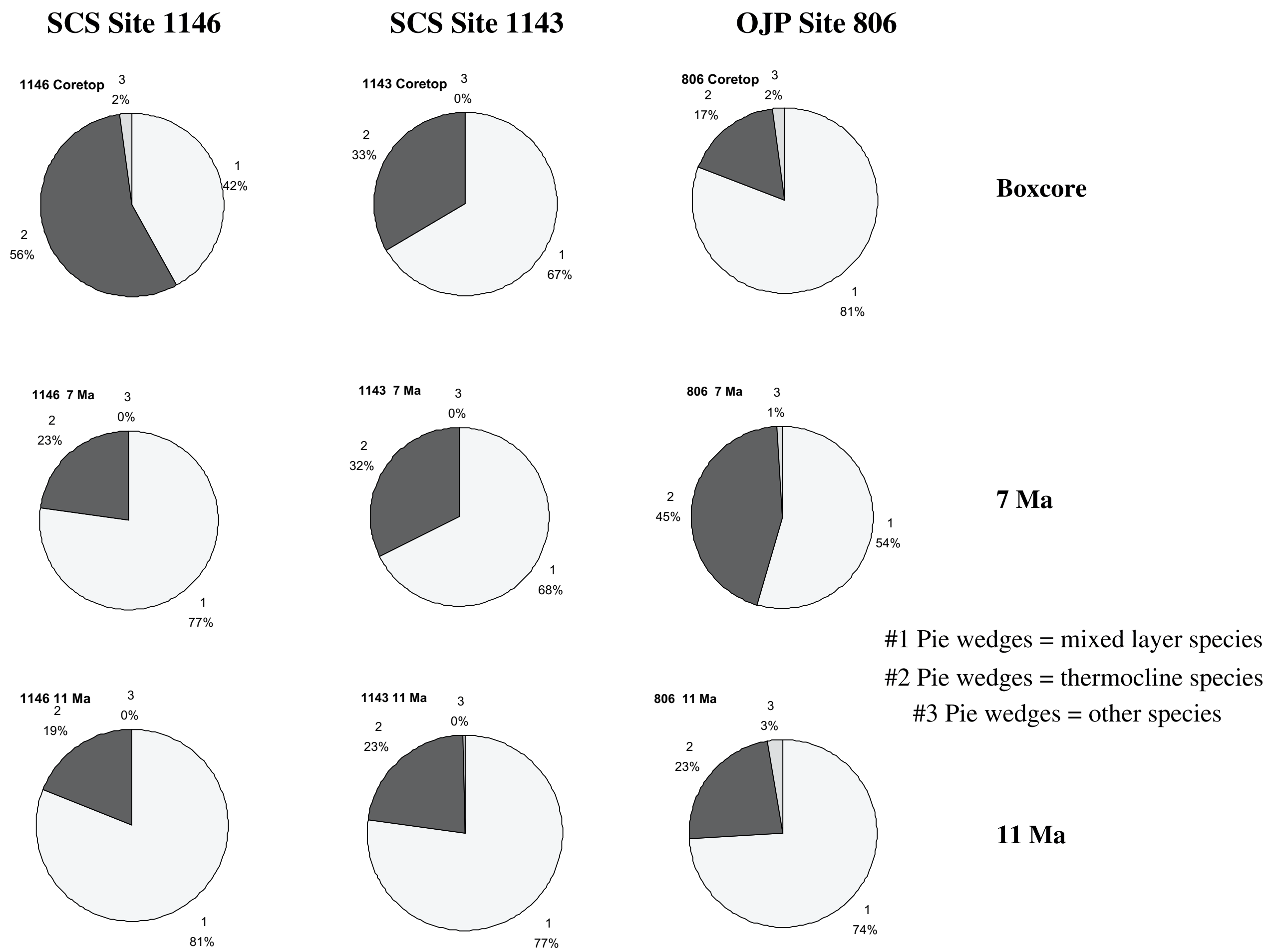

Figure 3. Pie diagrams (above) depict planktic foraminiferal population analyses at three time slices (0, ~7, ~11 Ma) at 3 sites (ODP Sites 1146, 1143, 806; note, boxscores are from Sonne 95-19757, Sonne 95-19733 and MW 2.5-BC-37, respectively; ancient samples correlated using planktic foraminiferal and calcereous nannofossil biostratigraphy). The populations present in each sample were classified as mixed layer or thermocline dwelling based on calibration with stable isotope paleoecology (Nathan, 2001) and the existing literature.

The coretop near Site 806 in the western equatorial Pacific (Ontong Java Plateau; OJP) shows a **dominance of mixed layer species** (81%) with the thermocline species contributing significantly less (17%), indicating the modern **Western Pacific Warm Pool** (thick mixed layer, deep thermocline, low productivity and low seasonality). In contrast, the coretop near Site 1146 in the northern South China Sea shows the dominance of thermocline dwellers (56%) with significantly less mixed layer species (42%), which points to the strong seasonality (East Asian Monsoon) and higher productivity. The assemblages at 7 and 11 Ma are considerably different. Specifically, OJP Site 806 assemblages at 7 Ma imply the lack of a WPWP and greater productivity and/or seasonality as indicated by the abundance of thermocline dwellers (45%), while at 11 Ma, a "**proto-WPWP**" may have existed as indicted by the dominance of the surface dwelling assemblage (74%). Warm pool-like conditions may have characterized parts of the South China Sea in the late Miocene prior to the intensification of the East Asian Monsoon.