Emily Browning received support from us for her M.S. At this time, she is a PhD candidate at the University of Massachusetts under the guidance of Dr. Mark Leckie. The focus of her program at UMass includes combining calcareous nannofossil paleoecology with foraminifera population and stable isotope analysis to solve paleoceanographic problems. she received her Master's degree from the University of Nebraska under the guidance of Dr. David Watkins with a specialty in nannofossil paleoecology and biostratigraphy. She was a shipboard scientist on Leg 307 of the Integrated Ocean Drilling Program.

THE MIOCENE *RETICULOFENESTRA* EVENT, OCEAN GATEWAYS, AND CHANGES IN TROPICAL PRODUCTIVITY

Dynamic climate changes during the middle to late Miocene originated from the tectonic constriction of the Indonesian and Caribbean gateways (Kennett *et al.*, 1985; Romine and Lombari, 1985; Savin *et al.*, 1985; Theyer *et al.*, 1989; Gasperi and Kennett, 1992, 1993a; Hodell and Vayavananda, 1993; and Norris *et al.*, 1993), uplift of the Himalaya and Andes mountain chains (Kutzbach *et al.*, 1989; Ruddiman and Kutzbach, 1989; Raymo, 1994), and glaciation of Antarctica (Kennett, 1977; Wright and Miller,1992, 1993; Miller *et al.*,1987; Flower and Kennett, 1993; and Billups and Schrag, 2002). Ultimately, these geologic events restricted equatorial circulation through tropical oceanic gateways (Kennett *et al.*, 1985; Droxler *et al.*, 1998; and Nathan and Leckie in review), increased continental weathering rates (Hodell *et al.*, 1991; Filippelli and Delaney, 1994; Filippelli, 1997; Martin *et al.*, 1999; Hermoyian and Owen, 2001; and Diester-Haass *et al.*, 2005), and caused eustatic sea level fluctuations (Vail *et al.*, 1977; Haq *et al.*, 1987; Hardenbol *et al.*, 1998; and Miller *et al.*, 2006). Fluctuating sea level also facilitated the burial of organic matter along biologically productive continental margins and marginal basins such as the South China Sea and Gulf of Mexico.

During the late middle to late Miocene, coinciding with these large scale geologic events, the carbon cycle underwent major changes that affected deep-sea carbonate preservation and production, including anomalous events known as the 'carbonate crash' (~12-9 Ma) and 'biogenic bloom' (~9.3-4.0 Ma). The most significant reorganization of the tropical nannofossil assemblages during the Neogene (Bown, 1999) coincided with the waning stages of the 'carbonate crash' and initiation of the 'biogenic bloom'. The **Miocene *Reticulofenestra* event (MRE)** denoted the worldwide collapse in the relative abundance of the prominent calcareous nannofossil genus *Reticulofenestra* (Figure 1a; Rio *et al.*, 1990; Young *et al.*, 1990; Takayama, 1993; Raffi and Flores, 1995; Backman and Raffi, 1997; and Kameo and Bralower, 2000). This event, as manifested by both the abrupt crash in abundance and gradual recovery of small *Reticulofenestra* species (Figure 1a,b,c), is widely known from tropical deep-sea drill sites as the paracme of *Reticulofenestra pseudoumbilicus* (i.e., disappearance of large forms of the genus).

The **MRE** has been documented extensively in academic and ocean drilling literature; however, the timing, nature, and mechanism(s) responsible for this threshold-like event remain a mystery. It is compelling to us that this perturbation in tropical nannofossil assemblages coincides with fundamental changes in the carbon cycle. Is it a coincidence that the **MRE** occurs just as the 'carbonate crash' was ending and 'biogenic bloom' beginning, or is the **MRE** somehow linked to these fundamental changes in carbonate accumulation? The MRE also coincides with a major phase of uplift of the Himalayas and Andes (Kutzbach *et al.*, 1989; Ruddiman and Kutzbach, 1989; Raymo, 1994; and Martin *et al.*, 1999), and the reinvigoration of equatorial circulation through the Indonesian and Caribbean gateways (Nathan and Leckie, in review).

The **MRE** has been documented in the Indian Ocean (Young, 1990: various DSDP Sites; Mock, 1999: ODP Site 251), western equatorial Pacific (Takayama, 1993: ODP Sites 805-806), eastern equatorial Pacific (Rio *et al.*, 1990; Raffi and Flores, 1995; Mock, 1999: ODP Sites 844-854), Caribbean (Kameo and Bralower, 1993: ODP Sites 998, 999), and the Atlantic (Gartner, 1992: DSDP Site 608; Backman and Raffi, 1997: ODP Site 926). The **MRE** is characterized by an abrupt collapse in the relative abundance of *Reticulofenestra* (Figure1a), followed by a more gradual increase in the abundance of small forms at the expense of the larger forms (Figure 1b). The recovery of *Reticulofenestra* following the collapse in relative abundance is marked by a dominance of small and very small forms (Figure 1b). Large forms of *Reticulofenestra* eventually return in abundance; however, throughout the remainder of the Neogene they make-up an almost insignificant portion of tropical nannofossil assemblages. A high-resolution (~3 kyr) record through the **MRE** at Site 806 in the western equatorial Pacific shows an abrupt disappearance of the previously dominant *Reticulofenestra* at ~ 9.2 Ma (Figure 1c).

(1) Our principle working hypothesis is that the collapse in the relative abundance of *Reticulofenestra* (~9.3-9.2 Ma) and subsequent recovery and dominance of small (5-3 μm) and very small (<3 μm) forms at the expense of large (>7 μm) forms is associated with changes in surface water nutrient conditions.

The 'biogenic bloom' is bimodal: one peak at ~9.3-9.0 Ma and a second stronger peak centered at 6.5-5.0 Ma (Hermoyian and Owen, 2001). We hypothesize that the **MRE** is initiated by the first peak, or nutrient pulse, of the 'biogenic bloom'Although the 'biogenic bloom' is a complex event in need of further investigation, the principle reason for the observed increase in productivity during this event is most likely related to an overall increase in nutrient flux to the world ocean (Filippelli and Delaney, 1994; Filippelli, 1997; and Martin *et al.*, 1999). In this study, special consideration must be given to the dominance of small *Reticulofenestra* following the initial crash in relative abundance of *Reticulofenestra*. Nannofossils dominating assemblages in high nutrient conditions tend to be small sized (3-5 μm) placoliths, which inhabit the uppermost photic zone (*e.g.*, Okada and Honjo, 1973, Takahashi and Okada, 2000, Bauman and Freitag, 2004). Small *Reticulofenestra* dominate modern nannoplankton assemblages in high nutrient conditions (Okada, 2000), and dominance of these taxa in Pleistocene assemblages denote eutrophication (Okada and Honjo, 1973; Okada, 2000; Takahashi and Okada, 2000, Kameo, 2002, Bauman and Freitag, 2004). Does the dominance of small *Reticulofenestra* in the MRE represent a massive coccolithophorid 'bloom'? Preliminary isotopic evidence from the **MRE** at ODP Site 806 in the western equatorial Pacific shows that surface water fertility increased as nutrient-rich (^{12}C-rich) thermocline waters upwelled into the photic zone (Figure 1a).

(2) The MRE is triggered from sea level rise during the late Miocene, which reinvigorated tropical circulation through the Indonesian and Caribbean gateways, thus reestablishing interbasinal upper water column communication, including the dispersal and upwelling of nutrients across the tropics.

Although Hypothesis #1 posits the **MRE** results from increased nutrients from the weathering of the Himalayas and Andes, we offer an ancillary hypothesis to explain the tropic-wide dispersal of these nutrients. During the middle to late Miocene, the actively closing Indonesian and Caribbean gateways act like valves on inter-basin tropical circulation. Nathan and Leckie (in review) propose that these 'gateway valves' are modulated by fluctuating sea level. The **MRE** at ~9.3-9.2 Ma occurs as sea level rose following the end of the Mi5/Mi6 glaciation (~11.6-10.4 Ma), resulting in reinvigoration of both Indonesian and Central American Seaway through-flow (Nathan and Leckie, in review). Could the reinvigoration of inter-basin circulation have facilitated upper water column mixing and the dispersal of nutrients across the tropics (Hypothesis #1), and forced the nannoplankton community across a stable threshold?

METHODS

The rapid onset of the **MRE** and gradual recovery of *Reticulofenestra* abundance resemble a pattern of change that was triggered by an abrupt event, such as a threshold event in the ocean-climate system *(e.g.*, Berger, 1982). Our research strategy will be to use several independent and complementary proxies to decipher changes in upper water column characteristics associated with the **MRE**. We also plan to provide high resolution chronostratigraphic and biostratigraphic correlation of the **MRE** across the tropics and in the South China Sea. This study will examine the **MRE** in carefully selected Ocean Drilling Program (ODP) sites from the western equatorial Pacific (ODP Site 806), Caribbean (ODP Site 1000-analog for the Gulf of Mexico), equatorial Atlantic (ODP Site 926), equatorial Indian Ocean (ODP Site 709), and northern South China Sea (ODP Site 1146). These sites will be used to explore inter-basinal similarities and differences in the timing, structure, duration, and hydrography of the **MRE** in the tropics of each ocean basin, and in the South China Sea and Gulf of Mexico (analogous ODP Site 1000 in the Caribbean), basins with vast hydrocarbon potential (*e.g.*, Thompson and Abbott, 2003). These sites have been chosen based on the presence of the **MRE** event, preservation conditions, location, high carbonate accumulation rate, as well as chronostratigraphic control based on the integration of biostratigraphy, paleomagnetic stratigraphy, orbitally-tuned stratigraphy, and/or carbon isotope stratigraphy. Nannofossil percent and absolute abundance, a combination of multi-species isotopic analyses and planktic foraminiferal population counts, $\delta^{18}O$ and $\delta^{13}C$ gradients between species of different water layers, and Sr/Ca ratios of bulk nannofossil rich carbonate will be used to measure nannofossil productivity (Stoll and Schrag, 2001; Stoll *et al.*, 2001).

Anticipated Significance

The most significant nannofossil event of the Neogene coincides with major changes in the carbon cycle during the late Miocene (end of the carbonate crash' and onset of the 'biogenic bloom'), the transition from a lowstand to highstand, the increasing constriction of tropical oceanic gateways, and uplift of the Himalayas and Andes. This study will investigate if the combination of these large scale geologic events facilitated an increase in nutrient delivery across the tropics, thereby stimulating a widespread increase in productivity and forcing a collapse in the abundance of the calcareous nannofossil genus *Reticulofenestra.* Implications for petroleum research include a detailed stratigraphic timing of the **MRE**, and investigation of productivity changes in the late Miocene associated with perturbation of the carbon cycle. The onset of the 'biogenic bloom' in the late Miocene was a major phase of organic carbon production and burial likely triggered by the interplay of tectonics, climate, and ocean circulation.

Miocene *Reticulofenestra* Event (MRE)

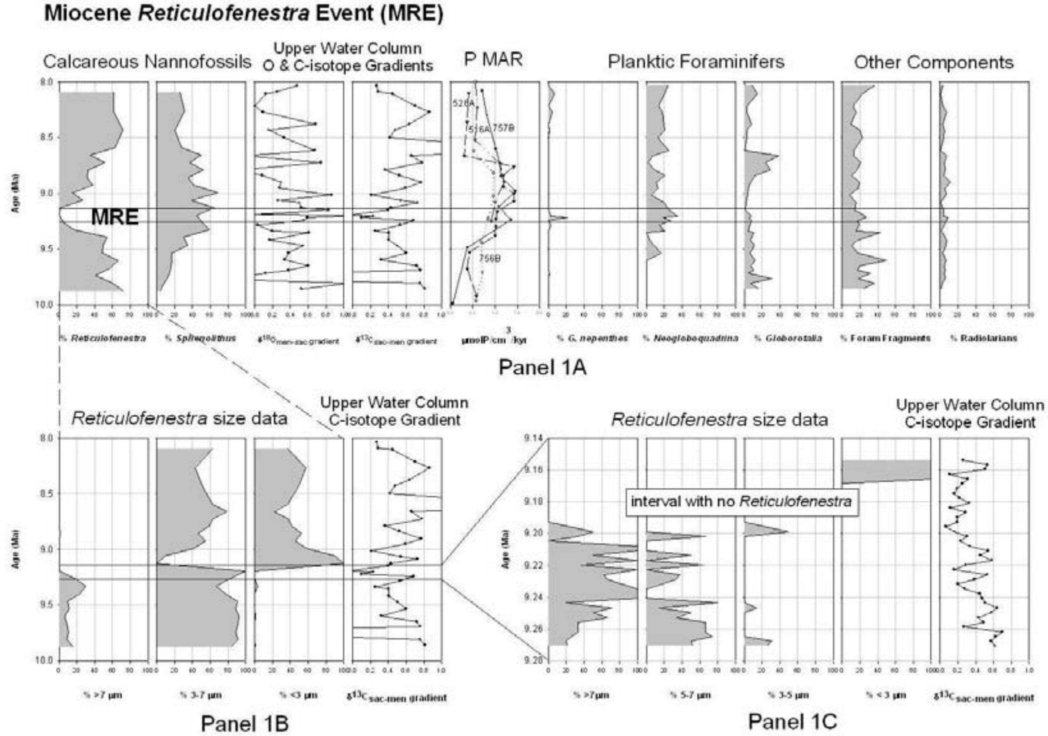

Figure1: Late Miocene record at ODP Site 806 in the western equatorial Pacific. The black horizontal lines from ~9.3-9.2 Ma highlight the **MRE** interval. **Panel A:** Low resolution data derived from ~10-8 Ma; nannofossil data from Takayama, 1993; $\delta^{18}O$ and $\delta^{13}C$ data from Nathan, 2005; phosphorous mass accumulation rates from Hermoyian and Owen, 2001; foraminifera population and radiolarian data from Nathan, 2005. **Panel B:** Low resolution data derived from ~10-8 Ma: *Reticulofenestra* size data from Takayama, 1993. **Panel C:** High resolution time slice examined within the **MRE** interval (9.28-9.14 Ma); nannofossil data from Browning research in progress; $\delta^{13}C$ data from McLain, 2005.

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