[PS]Neogene Changes in Caribbean Paleoproductivity and Paleobathymetry of Deep-Sea Benthic Foraminifera, With Implications for the Gulf of Mexico*

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Abstract

The Miocene to Pliocene closure of the Central American Seaway had a profound impact on marine habitats and organisms in both the Caribbean Sea and the tropical eastern Pacific Ocean. With the gradual emergence of the Isthmus of Panama, a barrier between the Caribbean and Eastern Equatorial Pacific (EEP) was erected, preventing flow between the two regions. This study examines paleoproductivity values determined from deep-sea benthic foraminifera from the late Oligocene (~26 Ma) to early Pleistocene (~2.5 Ma), and tests the hypothesis that paleoproductivity values prior to closure of the Central American Seaway are similar in both the Caribbean and EEP, and then diverge around the time of early shoaling of the Isthmus of Panama. Benthic foraminiferal data from Caribbean ODP Site 999 are examined in conjunction with previously published data from the Caribbean (DSDP Site 502) and EEP (DSDP Sites 503, 568, and 569). Prior to the differentiation in the bottom-water source for the Caribbean and EEP (~16 Ma), they showed similar trends in organic carbon flux as measured by the Benthic Foraminiferal Accumulation Rate (BFAR). The time of the initial differentiation in bottom water is marked in the Caribbean with a sharp decrease in BFAR, followed by a large increase. When significant constriction of the seaway occurred approximately 8 Ma, Caribbean values of paleoproductivity (as recorded by increases in oligotrophic indicator species) markedly decreased and diverged from EEP values. With complete closure of the Central American Seaway (~4 Ma), the Caribbean sites showed a decrease in BFAR values and thus paleoproductivity, supporting the conclusion that without surface exchange with the nutrient-rich EEP, and together with a projected decrease in Caribbean circulation and upwelling, the Caribbean Sea established its modern oligotrophic regime. Later studies have found that the species composition and dominant species in the Caribbean were very similar to that of deep waters in the Gulf of Mexico, so that the Gulf of Mexico should yield similar results. Paleobathymetric and paleoenvironmental reconstructions were also conducted for the Caribbean samples, based on known benthic foraminiferal preferences that are also currently in use in the Gulf of Mexico.

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NEOGENE CHANGES IN CARIBBEAN PALEOPRODUCTIVITY AND PALEOBATHYMETRY OF DEEP-SEA BENTHIC FORAMINIFERA, WITH IMPLICATIONS FOR THE GULF OF MEXICO

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Abstract

The Miocene to Pliocene closure of the Central American Seaway had a profound impact on marine habitats and organisms in both the Caribbean Sea and the tropical eastern Pacific Ocean. With the gradual emergence of the Isthmus of Panama, a barrier between the Caribbean and Eastern Equatorial Pacific (EEP) was erected, preventing flow between the two regions. This study examines paleoproductivity values determined from deep-sea benthic foraminifera from the late Oligocene (~26 Ma) to early Pleistocene (~2.5 Ma), and tests the hypothesis that paleoproductivity values prior to closure of the Central American Seaway are similar in both the Caribbean and EEP, and then diverge around the time of early shoaling of the Isthmus of Panama. Benthic foraminiferal data from Caribbean ODP Site 999 are examined in conjunction with previously published data from the Caribbean (DSDP Site 502) and EEP (DSDP Sites 503, 568, and 569).

Prior to the differentiation in the bottom-water source for the Caribbean and EEP (~16 Ma), they showed similar trends in organic carbon flux as measured by the Benthic Foraminiferal Accumulation Rate (BFAR). The time of the initial differentiation in bottom water is marked in the Caribbean with a sharp decrease in BFAR, followed by a large increase. When significant constriction of the seaway occurred approximately 8 Ma, Caribbean values of paleoproductivity (as recorded by increases in oligotrophic indicator species) markedly decreased and diverged from EEP values. With complete closure of the Central American Seaway (~4 Ma), the Caribbean sites showed a decrease in BFAR values and thus paleoproductivity, supporting the conclusion that without surface exchange with the nutrient-rich EEP, and together with a projected decrease in Caribbean circulation and upwelling, the Caribbean Sea established its modern oligotrophic regime. Later studies have found that the species composition and dominant species in the Caribbean were very similar to that of deep waters in the Gulf of Mexico, so that the Gulf of Mexico should yield similar results.

Introduction

When Central America was emplaced between North and South America in the Neogene, it provided a major barrier to dispersal amongst tropical marine populations that, prior to the rise of the isthmus, had no major restrictions in neotropical range. With similar water chemistry, food availability and temperature, the pre-isthmus tropical Eastern Pacific (EEP Sites 503, 568 and 569) is predicted to have had similar paleoproductivity values to those in the Caribbean (ODP Sites 502 and 999) until a barrier sufficient to impede flow existed. This study tests the hypothesis that paleoproductivity proxies showed the effects of the closure of the Central American Seaway during intervals of previously identified geologic and paleoceanographic changes. Atlantic-Pacific divergence, increases or decreases are discussed in terms of the effect each event had.

The time intervals used are:

~16 Ma – Differentiation of bottom water source between the Caribbean and equatorial Eastern Pacific (EEP), with North Atlantic Deep Water occupying the Caribbean (Morrison and Nowlin, 1982; Keller and Barron, 1983; Duque-Caro, 1990; and Haddad and Droxler, 1996).

~12 Ma – Deep circulation barrier between the two regions (Duque-Caro, 1990)

~8 Ma – Pronounced seaway constriction (Wright et al., 1991, Billups, 2002).

~4 Ma – Complete closure of the Central American Seaway (Keigwin, 1978; Haug and Tiedemann, 1998).

Figure 1. Site locations

	Caribbean		Eastern Equatorial Pacific		
ODP/DSDP Site	999	502	503	568	569
Water Depth Drilled (m)	2828	3051	3672	2010	2744
Number of Samples (utilized in this study)	37	12	11	24	20
Minimum Specimen Number per Sample	126	15	49	1	1
Maximum Specimen Number per Sample	995	659	335	382	424
Average Specimen Number per Sample	350	326	154	103	125
Minimum Number of Species per Sample	28	8	24	1	1
Maximum Number of Species per Sample	70	62	63	61	67
Average Number of Species per Sample	44	43	39	21	28

Table 1. Site and foraminiferal data set

Methodology

This study utilizes data from sites (Fig. 1) drilled by the Ocean Drilling Project (ODP) and Deep Sea Drilling Project (DSDP). The current study incorporates new benthic foraminiferal data from Caribbean ODP Site 999, with previously studied data from Caribbean DSDP Site 502 and equatorial Eastern Pacific (EEP) sites 503, 568 and 569.

All analysis and interpretations of paleoproductivity follow the methodology of Jain (2006) and Jain and Collins (2007. Individual species counts from all sites were used in calculating the following paleoproductivity proxies:

- **BFAR**, Benthic Foraminifer Accumulation Rate – number of foraminifers/cm^2/kyr. Indicates productivity as seen in seafloor carbon flux since correlated with surface water productivity.
- **Oligotrophy** – indicated by relative abundance of *Nuttalides umbonifera* and abundances of low-organic-flux species.. Indicates decreased food supply and low seasonality , therefore low-organic-flux.
- **Mesotrophy** – indicated by relative abundance of *Epistominella exigua* . Indicates pulsed phytodetrital input and can tolerate a wide range of organic flux rates.
- **Eutrophy** – indicated by relative abundance of high-organic-flux species. Indicates eutrophic conditions based on modern associations of species.
- **Infaunal/Epifaunal ratio** of species – based on microhabitat preferences documented in literature (e.g., Corliss, 1985; Gooday and Rathburn, 1999).

Because of lack of data on previously studied sites, and lack of compatibility of sampling/counting methods, this study calculated BFAR only for ODP Site 999. For comparison of overall trends, published BFAR values calculated by Bornmalm (1997) for Site 502 and 503 are shown (Fig. 2); however, those values used counts from the 125µ sieve, and therefore, missed the smaller species and juveniles found in the >63µ size fraction of this study. Paleobathymetry determined by published preferences of microhabitat of species.

Results and Discussion

~16 Ma - Differentiation of Bottom-Water Source– Increase, then decrease of Nuttalides umbonifera at ODP Site 999 indicator of Antarctic Bottom Water (Corliss 1985); high carbonate corrositivity or low food supply (Loubere, 1991; Gooday, 1994; Nomura, 1995; Schmiedl, et al., 1997; Singh and Gupta, 2004). The interval before the event at ~16 Ma contains fluctuating values of BFAR, higher compared to intervals younger than ~12 Ma. Likely the result of change in the source of bottom water affecting food availability, and increasing corrosivity, allowing for more dissolution resistant species to flourish.

~12 Ma - Barrier to Deep Circulation– based on peak increase of Epistominella exigua, a pulse of phytodetritus and an increase in primary productivity. Barrier most likely had an impact on both EEP and Caribbean sites. In the EEP, increase in paleoproductivity (eutrophic and mesotrophic indicator species, while the Caribbean had delayed reaction with a decrease in paleoproductivity, followed by a resurgence at ~10.5 Ma to very high levels.

~ 8 Ma - Seaway Constriction - Both Caribbean sites diverged from similar values in abundance of oligotrophic species from the EEP sites. Sharp decrease in low-flux-indicator species at EEP Site 569 and steady increase at Caribbean Site 999. The Caribbean sites become oligotrophic (this study, Jain and Collins 2007). Seaway constriction prevented high levels of nutrients from reaching the sea floor in the Caribbean, resulting in a higher percentage of low-organic-carbon-flux species.

~4 Ma - Closure of the Central American Seaway - Complete closure of the seaway prevented high-organic-carbon fluxes, seen by changes in eutrophic and oligotrophic indicator species. The sharp increase in BFAR at Caribbean Site 999 is the result of a large influx of N. umbonifera, indicates increased input of food source. Calculations support the findings by Jain and Collins (2007), who concluded that closure of the CAS resulted in nutrient depleted and oxygen rich waters in the Caribbean. Suggested that with increased oxidation of available food, reduced amount of paleoproductivity. Current study also found a depletion of nutrient-rich waters. The increase in BFAR likely due to the overwhelming presence of N. umbonifera, a low-organic-carbon-flux species.

Paleobathymetric and paleooceanographic results show majority of study sites were bathyal, with Normal, and Marine. Study identified changes in water mass characteristics, showing presence of NADW, PIW, and AABW.

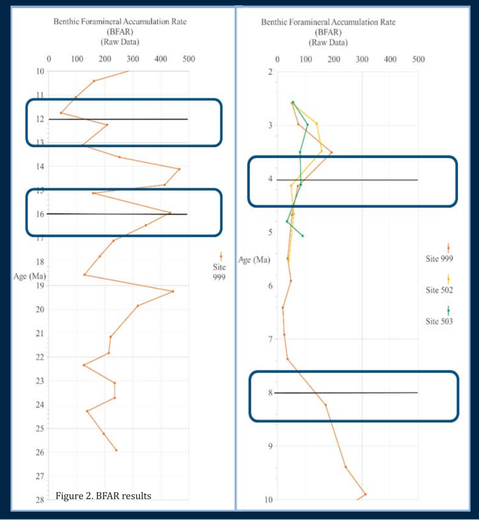

Figure 2. BFAR results

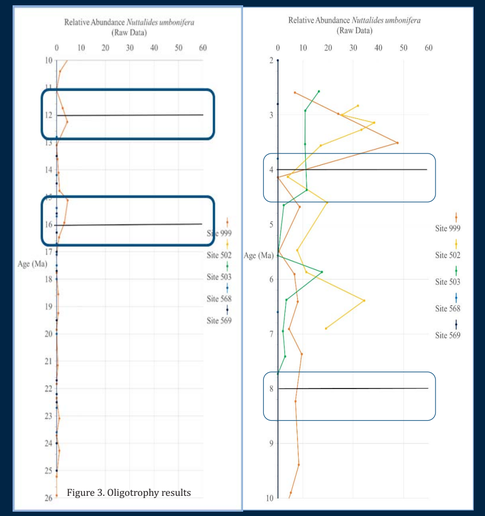

Figure 3. Oligotrophy results

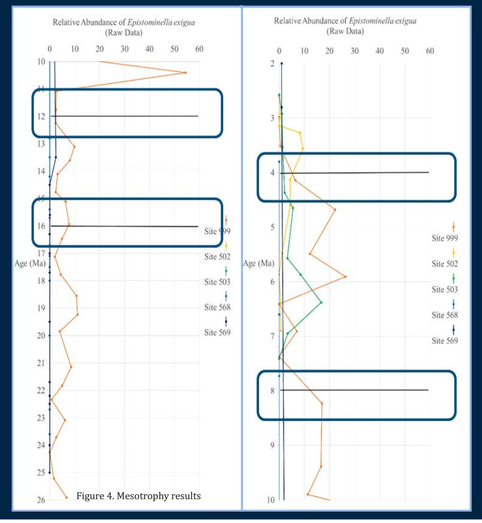

Figure 4. Mesotrophy results

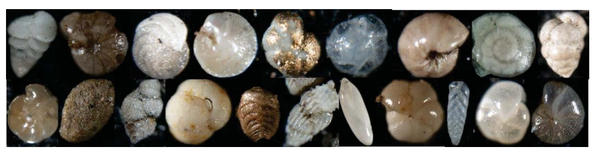

Figure 5. Species common to Caribbean and Gulf of Mexico

Conclusions

Examining the full Neogene history of paleoproductivity in the Caribbean versus the equatorial Eastern Pacific provides a baseline in values for the full effects of the constriction and gradual closure of the Central American Seaway that previous studies of the pre-8-Ma interval (Bornmalm, 1997; Jain and Collins, 2007; Jain et al., 2007) did not cover. The geologic events affecting seaway closure that were noted in previous studies (Keigwin, 1978; Keller and Barron, 1983; Duque-Caro, 1990; Haug and Tiedemann, 1998) can be seen in the paleoproductivity indicators examined here.

Prior to the bottom-water source differentiation at ~16 Ma, there were similar trends in oligotrophy and eutrophy for the Caribbean and EEP. Once there was an differentiation in bottom-water source, some interoceanic trends were noted in the proxy data. Presently, North Atlantic Deep water has been found to enter the Colombian Basin between Jamaica and Hispaniola (Morrison and Nowlin, 1982; Haddad and Droxler, 1996). Prior to the differentiation of bottom-water source, Caribbean Site 999 had the highest Paleoproductivity values of the study interval. While BFAR fluctuated through the rest of the study interval with multiple increases and decreases, overall averages of BFAR decreased in each interval. In the time interval after the deep-circulation barrier at ~12 Ma, the Caribbean showed pulses of phytodetrital material, while the EEP had an increase in paleoproductivity evidenced by increases in eutrophic and mesotrophic species. When there was a constriction of the seaway at ~8 Ma, Caribbean and EEP sites diverged in organic carbon flux values, with the Caribbean undergoing major decreases in high-organic flux and decreases in. The complete closure of the CAS at 4 Ma is seen in the Caribbean with marked decreases in multiple paleoproductivity leading to the conclusion that without the nutrient-rich EEP waters, the Caribbean attained the level of oligotrophy that has continued until present. More recent studies have noted that species composition of the deep waters of the Gulf of Mexico are similar to that of the Caribbean so similar results are expected in terms of paleoproductvity and other measurements.

Figure 6. Primary site relative to Gulf of Mexico

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