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# Variability of foraminiferal stable isotope ratios in Caribbean shallow waters of Panama: A modern framework for Neogene studies

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ABSTRACT

Oxygen and carbon isotope analyses of the foraminifera *Orbulina universa* (planktic), *Uvigerina peregrina* (benthic) and *Cibicides pachyderma* (benthic) in 45 bottom samples from the archipelago of Bocas del Toro, Caribbean Panama, are used to address the reliability of stable isotope values in distinguishing differences among neritic surface water and middle neritic to upper bathyal depths. The significance of variation in isotope values within stations, between stations within depth-defined groups, and between depths was determined with Analysis of Variance. Isotope values differ significantly among stations with few exceptions; thus, within-station error is minimal. $\delta^{18}O$ values of *O. universa* across the open shelf are the same. Oxygen isotope ratios of *U. peregrina* discriminate outer shelf to upper slope depths well. $\delta^{18}O$ values of *C. pachyderma* from the inner middle shelf, outer middle shelf, and inner outer shelf are significantly different, and mean values from 33 m to 240 m are strongly correlated with water depth. *Cibicides pachyderma* from two stations shows strong $\delta^{18}O$ evidence of downslope transport of 80 and 160 m, corroborated by foraminiferal assemblages. $\delta^{13}C$ can only differentiate middle shelf and outermost outer shelf to upper slope depths. Oxygen isotope values of *O. universa* and *U. peregrina* generally agree with predicted temperatures, and those of *C. pachyderma* are consistently low. Comparisons of $\delta^{18}O$ values of benthic and planktic foraminifera, and neritic and deep-sea planktic foraminifera, enable qualitative and even quantitative estimates of paleodepth and paleosalinity, enabling their use in Neogene studies of sedimentary rocks within the region.



## 1. Introduction

The stable isotopes of oxygen and carbon preserved in foraminiferal tests have been widely used to infer changes in paleoceanographic conditions such as temperature, salinity and water composition (e.g., Emiliani, 1955; Shackleton and Opdyke, 1973; Woodruff and Savin, 1989; Haug et al., 2001). Stable isotopes are preferentially applied to deep-sea and open-ocean waters because physical conditions there are more stable than those in shallow and nearshore waters, so that $\delta^{18}O$ and $\delta^{13}C$ values more closely approximate a regional or global signal. In recent years, more studies have investigated relationships between neritic marine conditions and stable isotopes of foraminifera. For example, several studies of marginal marine foraminiferal stable isotopes (Ingram et al., 1996a, 1996b; Reinhardt et al., 2003; Eichler et al., 2010, 2014) have established associations of $\delta^{18}O$ and $\delta^{13}C$ with salinity, temperature and patterns of freshwater and marine mixing. In neritic and especially nearshore waters, local differences in salinity, temperature, and carbon source can mask regional and global signals, complicating the interpretation of foraminiferal isotopic ratios. However, the neritic setting, rich in macrofossils, is where most evolutionary studies of marine organisms are based. A framework for interpreting neritic stable isotopes would allow better assessment of the impact of environmental change on evolution.

This study examines the correspondence of bathymetry, temperature and salinity to stable isotope values in planktic and benthic foraminifera from middle neritic to uppermost bathyal depths of the Bocas del Toro archipelago, Panama, southwestern Caribbean Sea (Fig. 1). We use Analysis of Variance (ANOVA) to investigate the variation of isotope values at a station, by testing whether isotopic variability is too great within stations to distinguish between stations, and whether isotopic values vary consistently according to bathymetry on the open shelf or offshore of islands, and to determine the ranges in isotopic values that can be expected at particular depth ranges in the region. The results are also used to investigate the influence of downslope transport on samples across a bathymetric gradient.

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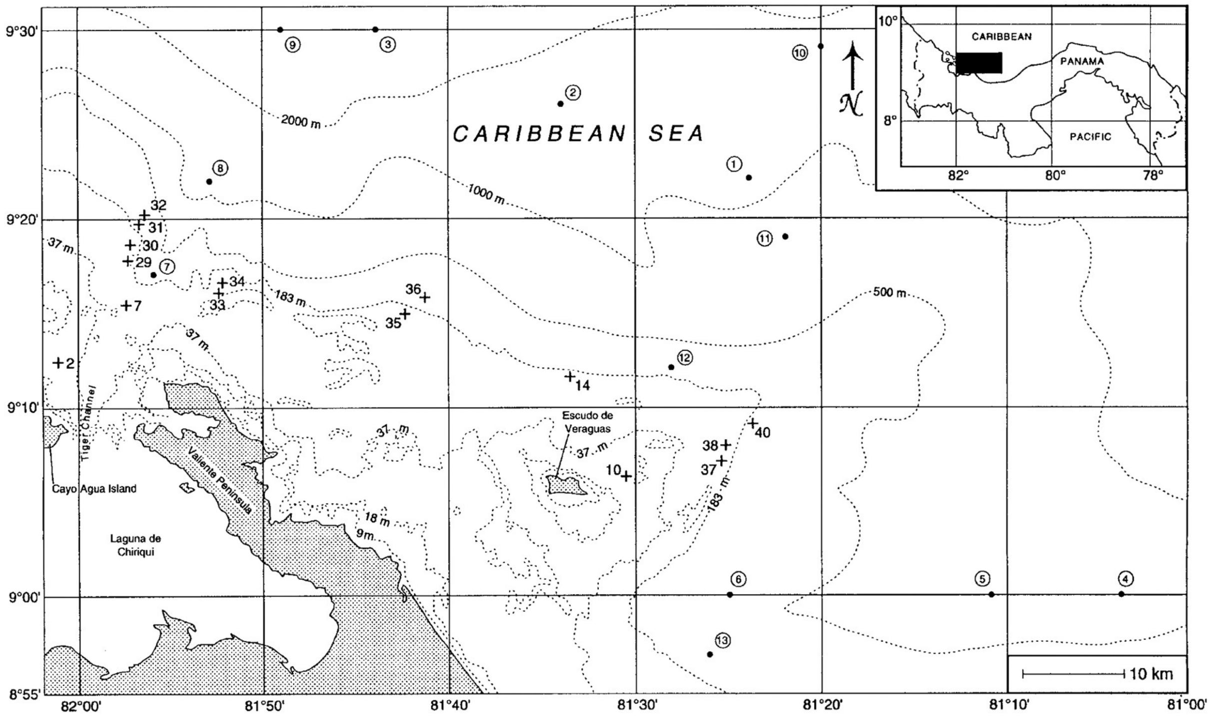


**Fig. 1.** Study area (black rectangle, inset) in the archipelago of Bocas del Toro, Panama. + = sample stations used in isotope analyses (Table 1). Circled numbers = U.S. Navy hydrographic stations (Table 2).

The need for a Neogene record of paleoceanographic change tied directly to the evolutionary record of shallow-water faunas of southern Central America motivated this project. The Neogene emergence of the Isthmus of Panama, which caused closure of the Tropical American Seaway connecting Caribbean and eastern Pacific waters, produced dramatic, large-scale evolutionary changes (Coates et al., 1992; Collins et al., 1996; Jackson et al., 1996; Collins and Coates, 1999; O'Dea et al., 2007) resulting in part from oceanographic change (Keigwin, 1982; Haug et al., 2001). An isotopic study of Recent foraminifera from Caribbean stations across the continental shelf of western Panama provides a framework for interpreting isotopic values of fossil foraminifera from this and similar tropical settings such as southeast Asia.

### 1.1. Study area

Samples of bottom sediments were collected from the Bocas del Toro archipelago, Panama (Fig. 1, Table 1). Bocas del Toro lies between the Limón area of Caribbean Costa Rica and the Panama Canal area, all of which are included in ongoing isotopic studies of Neogene foraminifera

**Table 1**
Sample locations and water depths of Fig. 1.

| Station # | Latitude N | Long. W | Depth (m) |
|---|---|---|---|
| 2 | 9°12.6′ | 82° 1.0′ | 33 |
| 7 | 9°15.5′ | 81°57.6′ | 56 |
| 10 | 9° 6.4′ | 81°30.5′ | 35 |
| 14 | 9°11.5′ | 81°33.5′ | 90 |
| 29 | 9°17.9° | 81°57.3′ | 73 |
| 30 | 9°18.8′ | 81°57.1° | 120 |
| 31 | 9°19°8′ | 81°56.7′ | 168 |
| 32 | 9°20.2′ | 81°56.3′ | 230 |
| 33 | 9°16.0′ | 81°52.4′ | 80 |
| 34 | 9°16.6′ | 81°52.3′ | 120 |
| 35 | 9°15.0′ | 81°42.4′ | 180 |
| 36 | 9°15.8′ | 81°41°3′ | 235 |
| 37 | 9° 7.7′ | 81°25.3′ | 113 |
| 38 | 9° 8.7′ | 81°24.8′ | 164 |
| 40 | 9° 9°2′ | 81°23.9° | 240 |

and mollusks. The archipelago consists of Almirante Bay in the northwest, and the more freshwater-influenced Laguna de Chiriquí in the southeast (D'Croz et al., 2005). The region does not experience a clearly defined dry season, but on average, rainfall is less intense during January, March and October (http://worldweather.wmo.int/en/city.html?cityId=1245). Marine productivity is limited by the absence of significant upwelling; however, freshwater input via river discharge into the Laguna de Chiriquí contributes to significant, albeit modest, nutrient influx (D'Croz et al., 2005).

Sedimentation in Bocas del Toro is mixed siliciclastic and carbonate. Erosion of the Cordillera Central on the mainland is rapid in this region of extremely high rainfall (approximately 3 m/yr) and ambient humidity (Rodríguez et al., 1993), resulting in high rates of siliciclastic sedimentation. Rates vary considerably within shallow-water depositional regimes. For example, for the Bahía Almirante, the bay northeast of and adjacent to the Laguna de Chiriquí (Fig. 1), Aronson et al. (2014) used $^{210}$Pb to measure rates of sediment accumulation of 0.7–1.1 cm/yr. Rates have probably increased in the last 20 years as a result of land development on the larger islands (Guzmán et al., 2005). One might expect sediment accumulation rates in an open-ocean setting to be lower by 1–2 orders of magnitude, on the decadal to centennial scale. Neritic waters support a coral reef ecosystem that produces a large volume of carbonate sediments. The islands and peninsula of Bocas del Toro are composed primarily of fossiliferous Neogene sediments that are a primary source for research on evolution, biogeography, environmental change, and tectonic uplift associated with the emergence of the Isthmus of Panama and closure of the Central American Seaway (Collins, 1993; Jackson et al., 1993; Collins et al., 1995; Teranes et al., 1996; O'Dea et al., 2007; Smith et al., 2013).

The marine habitats we sampled were (1) offshore of islands (stations 2, 10), (2) in a channel between the lagoon and open continental shelf (station 7), (3) on the open shelf (stations 14, 29–35, 37), and (4) on the uppermost continental slope (stations 36, 38, 40) (Fig. 1). The Laguna de Chiriquí contains low-salinity waters, so the foraminiferal species of interest were not found there (see below). Hydrographic stations sampled by the U.S. Navy provided temperature and salinity data every 10 m from 0 m to ~250 m for different seasons and in