



Invited research article

Expanded Florida reef development during the mid-Pliocene warm period



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ABSTRACT

The coral fauna of the Tamiami Formation documents a northern expansion of reef development along the Florida Peninsula during the mid-Pliocene warm period (MPWP). Radiometric dating (U–Pb) of *Solenastrea bournoni* produced an age of 2.99 ± 0.11 Ma, constraining reef development to the MPWP and the peak of Plio-Pleistocene faunal turnover; subsequent to the final closure of the Central American Seaway (CAS) but prior to major Northern Hemisphere Glaciation (NHG). Coral faunal analyses are based on a total of 1614 coral specimens collected along a 165 km stretch of the west Florida coast, and included rarefaction and detrended correspondence analysis (DCA). A total of 60 coral species occur within the Tamiami Formation, with faunal assemblages ranging from 42 to 87% extinct taxa. The Tamiami collections can be split into a southern “reef” assemblage with high diversity of stenotopic taxa and a northern “non-reef” assemblage with lower diversity eurytopic taxa. The southern reef assemblage contains framework buildups of the dominant tropical taxa *Stylophora affinis*, *Orbicella annularis*, and *Acropora cervicornis*. We interpret enhanced west Florida reef development during the middle Pliocene to be a product of more equitable sea surface temperatures, and reduced salinity fluctuations associated with higher sea levels. While mean sea surface temperature estimates based on oxygen isotopic analysis of the coral *Solenastrea bournoni* (25.3 °C) are similar to present day values (26 °C), a completely flooded southern Florida Platform in the Pliocene would be less prone to salinity fluctuations associated with coastal runoff and extreme cold-water events during winter storms. While higher latitude range shifts of tropical reef corals associated with current global climate change have been documented elsewhere in the world, we do not foresee the West Florida Shelf being conducive to significant range shifts in tropical coral taxa or reef development within the coming century.

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1. Introduction

Coral reefs have changed dramatically over recent decades as a result of human overexploitation, pollution, and global climate change (Hughes et al., 2003; Pandolfi et al., 2003). Since climate warming is forecast to continue, predicting the impact of climate change on the abundance and distribution of reef corals has become relevant in establishing conservation priorities (Roberts et al., 2002; Brooks et al., 2006; Pandolfi, 2015). Most studies of climate change effects on corals have focused on temperature-induced coral bleaching and mass mortality in tropical areas. Optimum temperatures for coral growth are generally around 26 – 27 °C (Clausen and Roth, 1975; Jokiel and Coles, 1977; Marshall and Clode, 2004). While bleaching thresholds vary by region and can be influenced by other environmental factors (light, salinity, biological), they typically range between 28.3 and 30.2 °C (Hoegh-

Gulberg, 1999). Extreme cold water can also influence photosynthetic efficiency, and result in coral bleaching and mortality (Saxby et al., 2003; Hoegh-Gulberg et al., 2005; Lirman et al., 2011). Cold-temperature tolerances are not well defined for corals, but early experiments show that prolonged exposure to 16 °C is stressful to most species and that exposure to temperatures of 14 °C for as little as 9 h can result in coral mortality (Mayor, 1914; Mayor, 1918; Muscatine et al., 1991). The present-day global distribution of coral reefs generally coincides with the 18 °C monthly minimum seawater isotherm (Kleypas et al., 1999).

Average global sea surface temperatures are rising at a rate of 0.11 °C per decade (Rhein et al., 2013). While future increases may result in increased tropical bleaching, they may also result in poleward range shifts or expansions into temperate areas as lethal low temperature thresholds shift to higher latitudes. Evidence of the poleward range expansion of modern corals has been documented along the east coast of Australia (Baird et al., 2012), as well as the temperate areas of Japan (Takatsuki et al., 2007, Yamano et al., 2011). Coral range expansions have also

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been detected in the recent geologic past. Precht and Aronson (2004) documented an expanded northern limit of two cold-sensitive species, *Acropora palmata* and *Acropora cervicornis*, along the Florida east coast during the middle Holocene (10,000–6000 years ago), while Greenstein and Pandolfi (2008) document expanded ranges of tropical taxa along the coast of western Australia during the last interglacial period.

The modern coral fauna of the West Florida shelf is generally impoverished with minimal framework reef development (Hine et al., 2008). Here we document expanded reef development within the region during the mid-Pliocene warm period (MPWP). The MPWP ranges from 3.3 to 2.9 Ma, and is increasingly recognized as an important analog for future climate change (Robinson et al., 2008; Haywood et al., 2009). The MPWP represents the last time atmospheric CO₂ concentrations were in the range 350 to 450 ppm (Pagani et al., 2011). Model–data comparisons suggest that mean surface temperature was warmer than pre-industrial for the average interglacial climate state during the MPWP (Dowsett et al., 2012; Haywood et al., 2013). Global mean sea surface temperature (SST) is estimated at +1.7 °C above the 1901–1920 mean based on large data syntheses (Lunt et al., 2010; Dowsett et al., 2012), and general circulation model (GCM) results agree with this SST anomaly to within ±0.5 °C (Haywood et al., 2013).

Coral collections were made from the Tamiami Formation exposed between Naples and Sarasota along the west coast of Florida (Fig. 1). Faunal records were analyzed in combination with previously well-sampled Neogene coral localities of the Caribbean region to determine the pattern and timing of Neogene faunal changes, and to interpret the role of community structure in Plio-Pleistocene regional extinctions. We assess the environmental factors that may have contributed to diverse high-latitude reef development along the Florida Platform, and consider whether the Tamiami Formation provides a reasonable analog for expanded coral ranges and reef development associated with future climate change within this century.

2. Regional geology

The Tamiami Formation was first described by Mansfield (1939) as the Tamiami limestone. The name was proposed for fossiliferous, sandy limestones exposed at the surface and along the canal and borrow pits adjacent to the Tamiami Trail (U.S. 41) in Monroe and Collier Counties. Hunter (1968) formally proposed five lithostratigraphic members (Ochopee limestone member, Buckingham limestone member, Pinecrest sand member, Murdock Station member, and Bayshore Clay member) of the Tamiami Formation and placed the members into three successive concurrent range zones. Meeder (1979a) recognized a capping coralline-rich limestone in Collier and Lee Counties, Florida, later named the Golden Gate Reef member of the Tamiami Formation (Meeder, 1979b). The Golden Gate Reef member overlies skeletal sands of the Ochopee limestone, and was described as having two reef intervals separated by a distinct discontinuity surface. The top of the Golden Gate Reef member is an irregular surface exhibiting jointing, solution pipes, accretionary laminated crusts, root casts, and (dis)solution breccia. Based on Sr isotope analyses within core W-16242 near Sanibel Island, Missimer (2002) constrained the entire 35 m thick Tamiami Formation to between 4.95 and 1.95 Ma.

3. Materials and methods

3.1. U-Pb chemistry and mass spectrometry

The U-Pb method can be extremely useful in providing critical age constraints on relatively pristine materials that lie beyond the range of the U-Th chronometer (e.g. Denniston et al., 2008; Quigley et al., 2012). A widely recognized impediment to the U-Th dating of young corals is the susceptibility of their porous and metastable aragonite skeletons to open system behavior resulting in mobility of U or intermediate U-series daughter products. The exact nature of these processes is still much debated with no current consensus (Scholtz and Mangini, 2006). Despite the potential for open system behavior, if U-Pb isochrons can be obtained, it necessarily implies that any possible open-system behavior in the U-decay chain occurred relatively soon after deposition and was not long-lived. Furthermore, it is also important to note that most of the effects observed in the U-Th dating of corals lie well within the typical uncertainty bounds of U-Pb age determinations. An integrated approach was used to assess the potential for diagenetic alteration in our coral sample prior to dating, including: petrographic thin sectioning and electron microscopy (SEM), X-ray diffraction (XRD), and the stable isotopes of carbon and oxygen (see methods below).

We applied U-Pb geochronology to a single exceptionally preserved specimen of *Solenastrea bournoni* (CCD-54102) collected from the Tamiami Formation at locality CFO03. No other corals from our collection were deemed suitable for age dating or other geochemical analyses. The analytical methods employed in this study follow closely those published previously by Woodhead et al. (2006). Isotope ratios were determined on a Nu© Plasma MC-ICPMS using a DSN-100 desolvation unit and MicroMist glass nebuliser, operating in the range 50–100 µl/min uptake. Instrumental mass bias effects were monitored and corrected using NIST SRM 981 reference material in the case of Pb, and the sample's internal ²³⁸U/²³⁵U ratio (= 137.88) in the case of U. ²³⁸U/²⁰⁶Pb–²⁰⁷Pb/²⁰⁶Pb ages were calculated using the intersection of the isochron with an appropriate concordia, accounting for initial disequilibrium in the ²³⁸U and ²³⁵U decay chains (and employing a modern seawater ²³⁴U/²³⁸U ratio).

3.2. Petrographic and scanning electron microscopy

Standard petrographic microscopy and SEM were used to assess pristine coral preservation through the presence of coral micro-morphological features such as teeth and denticles as well as micro-structural calcification centers and radiating bundles of aragonitic fibers.

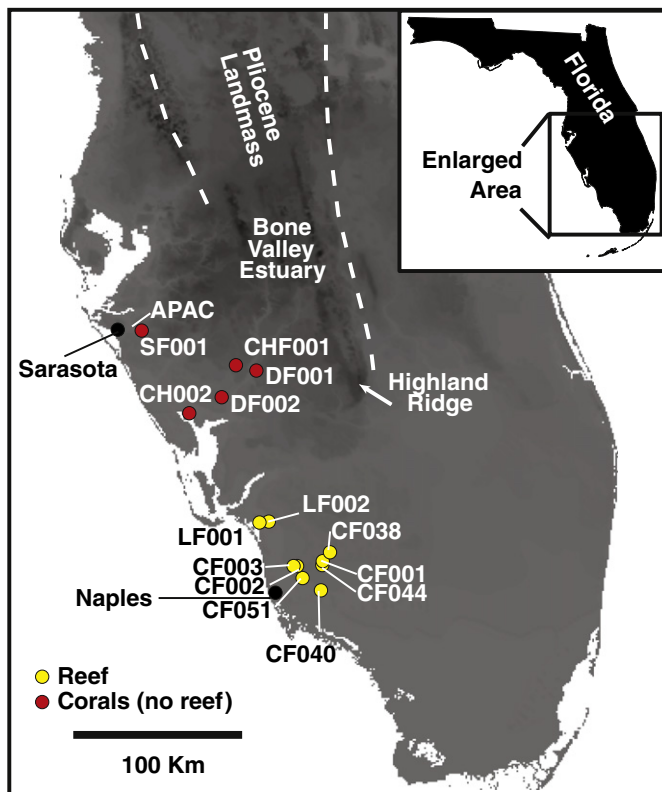


Fig. 1. Regional Map of southern Florida showing coral collection localities.

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