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Research paper

Santonian–Campanian planktonic foraminifera from Tanzania, Shatsky Rise and Exmouth Plateau: Species depth ecology and paleoceanographic inferences

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ABSTRACT

The Santonian–Campanian interval is of particular interest as it encompasses a cooling trend after the Late Cretaceous greenhouse maximum warmth of the Turonian as well as a possibly related major faunal turnover among planktonic foraminifera. The recovery of pristinely preserved planktonic foraminifera from Santonian–Campanian sequences in southeastern Tanzania allows examination of faunal changes and documentation of species-specific stable isotope ($\delta^{13}C$ and $\delta^{18}O$) signatures. These isotopic data are ideal for inferring species paleoecological preferences and for tracing major paleoceanographic changes. This study reports the first $\delta^{18}O$ and $\delta^{13}C$ data generated on "glassy" specimens of *Marginotruncana coronata*, *M. undulata*, *M. marginata*, and *M. pseudolinneiana* and *Sigalia carpatica*. Additional results from Shatsky Rise (Ocean Drilling Program Leg 198, Hole 1210B) and Exmouth Plateau (ODP Leg 122, Hole 762C) provide geographic control on species habitat preferences and paleoceanographic context. Isotopic analyses suggest that double-keeled species, including *Globotruncana bulloides*, *Contusotruncana fornicata*, *C. plummerae* and probably marginotruncanids, inhabited the surface mixed layer, whereas the biserial *Gublerina rajagopalani* was a permanent thermocline dweller. Thus, our study confirms recent suggestions that the depth-distribution models based on shell morphology and analogies with modern taxa are not applicable. At all the examined localities, changes in planktonic foraminiferal assemblages are used to define several ecological intervals, each one characterized by a distinctive taxonomic composition and/or increasing/decreasing species diversity. Combined geochemical and paleontological observations suggest that, by the middle–late Campanian, a stratified upper water column developed in Tanzania while less stratified and/or mesotrophic conditions prevailed at Shatsky Rise and Exmouth Plateau.

1. Introduction

The Late Cretaceous encompasses a prolonged greenhouse climate phase that was occasionally interrupted by short-lived environmental disturbances of regional to global scale (e.g., Oceanic Anoxic Events in the Cenomanian–Turonian and Coniacian–Santonian [Schlanger and Jenkyns, 1976; Jenkyns, 1980]). The Santonian–Campanian is a particularly important interval as it spans the transition from the thermal maximum reached in the Turonian (Huber et al., 1995, 2002; Clarke and Jenkyns, 1999; Wilson et al., 2002; Forster et al., 2007; Bornemann et al., 2008) to more temperate conditions (Cramer et al., 2009; Friedrich et al., 2012; Ando et al., 2013) and to a thermohaline circulation that was more like that of the modern day (Premoli Silva and Sliter, 1999). Specifically, the progressive opening of the tropical Atlantic gateway continents and/or restriction of east-west tropical connections are correlated with evidence for changing intermediate and deep water circulation patterns (Friedrich and Erbacher, 2006; Robinson et al., 2010; MacLeod et al., 2011) with enhanced formation of deep waters in the southern high latitudes (Poulsen et al., 2001; Frank et al., 2005; Robinson et al., 2010). These oceanographic changes led to reorganization of marine ecosystems and formation of well-developed faunal bioprovinces analogous to the present situation (Huber, 1992; Premoli Silva and Sliter, 1999). The changes also likely contributed to a major faunal turnover among planktonic foraminifera including extinction of the genera *Marginotruncana* and *Dicarinella* and diversification within the genera *Globotruncana*, *Globotruncanita* and *Contusotruncana* (Premoli Silva and Sliter, 1999).

Relatively few studies on the taxonomic composition of Santonian–Campanian planktonic foraminiferal assemblages are available in the literature, and no studies have been coupled with reliable species-specific stable isotopes ($\delta^{13}C$ and $\delta^{18}O$) analyses, mainly because: (1) DSDP (Deep Sea Drilling Project), ODP (Ocean Drilling Program) and IODP (Integrated Ocean Drilling Program) cruises recovered relatively few and discontinuous Santonian–Campanian stratigraphic sequences, and

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(2) the planktonic foraminifera from these deep-sea sites are diagenetically altered, complicating paleoenvironmental conclusions based on stable isotopic analyses.

Recovery of exceptionally well-preserved planktonic foraminifera from Santonian–Campanian sequences in Tanzania allows species-specific stable isotope measurements ($\delta^{13}C$ and $\delta^{18}O$) that likely preserve initial values and these geochemical observations can be coupled with examination of assemblage changes across the interval. Samples come from Tanzania Drilling Project (TDP) Sites 28 and 32 drilled in coastal southeastern Tanzania (Fig. 1). Results obtained from Santonian–Campanian TDP material are compared with paleontological and geochemical data inferred from coeval planktonic foraminiferal assemblages recovered at two low-to-mid latitude sites including (1) Shatsky Rise (ODP Leg 198, Hole 1210B; northwestern Pacific Ocean and (2) Exmouth Plateau (ODP Leg 122, Hole 762C; eastern Indian Ocean), to infer species habitat preferences across latitudes and reconstruct the paleoceanographic context at the examined localities. Additional stable isotope analyses on calcareous perforate benthic foraminifera from TDP Site 28, Hole 1210B and Hole 762C are used to characterize bottom water properties in the studied time interval.

2. Materials and methods

TDP Sites were drilled in southeastern Tanzania as part of the Tanzanian Drilling Project (TDP), an informal collaboration of researchers studying the Upper Cretaceous–Neogene stratigraphy, micropaleontology and paleoclimate (Nicholas et al., 2006; Jiménez Berrocoso et al., 2010, 2012). The first stratigraphic and sedimentologic synthesis after several drilling seasons was published by Nicholas et al. (2006). According to their study, Santonian–Maastrichtian sediments of southeastern coastal Tanzania belong to the Nangurukuru Formation, which represents the lowest formation of the Kilwa Group [informal name introduced by Schlüter (1997) and formally defined by Nicholas et al. (2006)] that is of Santonian to early Oligocene age. Sediment accumulation was induced by a period of increased subsidence of the passive continental margin from the Late Cretaceous to Paleogene.

Lithologically, the Nangurukuru Fm. is composed of olive/gray claystones mottled with yellowish orange sandy clay, with sandy layers being concentrated in the uppermost *Radotruncana calcarata* Zone (see Fig. 6 in Nicholas et al., 2006). Based on lithology, common occurrence of agglutinated foraminifera, much less common occurrence of calcareous benthic foraminifera and absence of macrofossils (with the exception of fragments of inoceramids), Nicholas et al. (2006) concluded that the Nangurukuru Fm. was deposited on an outer shelf to upper slope environment and estimated about 300–500 m water depth. The same depositional environment is indicated by Jiménez Berrocoso et al. (2010, 2012) based on the stratigraphic and sedimentologic analyses of Upper Cretaceous sediments recovered during the more recent drilling expeditions (2007–2008).

Cores from the TDP have yielded distinctly diverse assemblages of glassy-preserved foraminifera (Pearson et al., 2001; Handley et al., 2008; Falzoni and Petrizzo, 2011; Petrizzo et al., 2011; Wendler et al., 2011, 2013; Huber and Petrizzo, in press; MacLeod et al., 2013) and calcareous nannofossils (Bown, 2005; Bown and Dunkley Jones, 2006; Lees, 2007) extracted from Cretaceous to Neogene core sediment and soil samples (Jiménez Berrocoso et al., 2010, 2012). Planktonic foraminifera are generally common to very abundant with few samples containing rare to very rare specimens. Calcareous perforate and agglutinated benthic foraminifera are common to abundant, whereas miliolids are rare to absent. Rare ostracods were also found in most samples.

Planktonic and benthic foraminifera show moderate to excellent preservation (see specimens 1, 2 and 3 in Fig. 2) in the samples collected from TDP Sites 28 and 32. Nevertheless, glassy specimens (sensu Sexton et al., 2006) are relatively rare and confined to limited stratigraphic intervals. Stable isotope analyses from TDP samples were exclusively made on foraminifera with this glassy preservation to maximize the likelihood of reporting (and interpreting) initial depositional values.

TDP Site 28 was drilled in 2008 5 km SW of Lindi and 0.10 km S off the main road. The site was drilled to 95 m, with good recovery from 17 m to the bottom of the hole and low to moderate recovery from 17 m to the surface. From the bottom of the hole to 8 m depth, the main lithologies are olive gray, olive to green black and olive black siltstones and silty claystones. Lithologies from 8 m to the surface consist of dark yellow–brown, silty claystones with some intercalations of massive, calcareous sandstones (Jiménez Berrocoso et al., 2012).

TDP Site 32 was also drilled in 2008 4.5 km to the SW of Lindi, 0.20 km S off the main road and 2 km to the SE of TDP Site 28. The site was drilled to 59 m, with good recovery from the bottom of the hole to 17 m and very low recovery from 17 m to the surface. Lithologies of slightly laminated, olive gray claystone and greenish gray, silty claystone are monotonous from the bottom of the hole to 14 m. Overlying sediments from 14 m to the surface consist of pale yellowish–orange, well-lithified massive grainstones.

Hole 1210B was drilled during ODP Leg 198 on Shatsky Rise, a submarine plateau in the northwestern Pacific Ocean. The hole penetrated 377 m of sediments above basement. Late Cretaceous deposits were encountered from 218.72 mbsf (meters below seafloor) to the bottom of the hole. The succession is 158.28 m thick and consists of interbedded gray chert and white nannofossil ooze with foraminifera (Bralower et al., 2002). This study focuses on the mid- to upper Campanian stratigraphic interval recovered from the bottom of the hole (core 42H) to

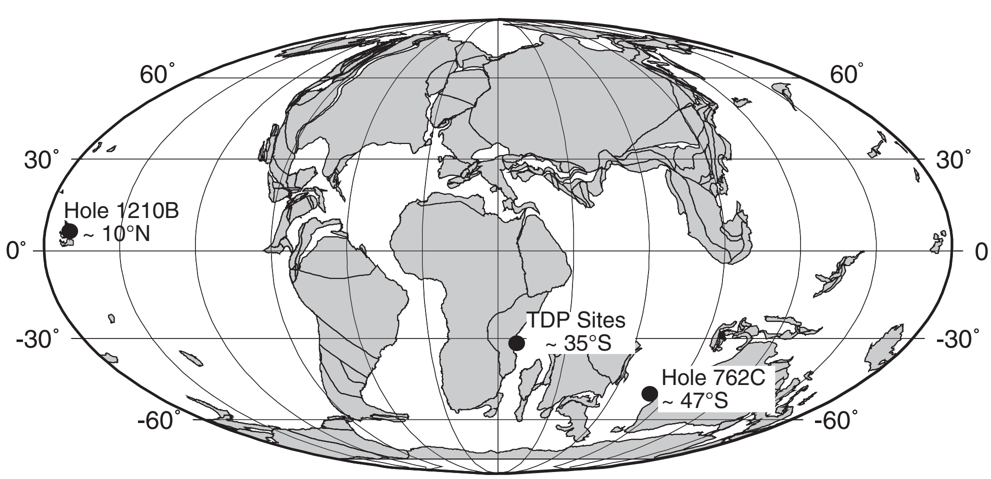

Fig. 1. Paleogeographic reconstruction for the mid-Campanian (80 Ma), with location and paleolatitude of sites examined during this study. After Hay et al. (1999).