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Sea-level reconstruction for Turonian sediments from Tanzania based on integration of sedimentology, microfacies, geochemistry and micropaleontology

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ABSTRACT

Despite many advances in sea-level research, the nature of cyclic eustatic sea-level fluctuations during warm periods without, or with much reduced, polar ice remains enigmatic. Recently published δ^{18}O records from extremely well-preserved Turonian microfossils from Tanzania do not support the contentious idea of glacio-eustatic control of global sea-level changes during the warmest period of the Cretaceous. For the same locality (site TDP 31) we reconstruct relative sea-level changes based on sequence stratigraphy and integration of sedimentology, microfacies, geochemistry, and micropaleontology. Four local sequence boundaries (SBs TuTz1–4) are recognized: at the base, middle, and top of the *Helvetoglobotruncana helvetica* Zone and in the Late Turonian. The lowstands are characterized by increased grain size, enhanced organic carbon flux, faunal assemblage changes, and bulk $\delta^{13}C_{org}$ and foraminiferal $\delta^{13}C_f$ and $\delta^{18}O_f$ minima. Strong benthic and planktic foraminiferal turnovers above the top Middle Turonian SB TuTz3 probably reflect shallowing (from upper slope to outer shelf) and/or eutrophication.

The TDP 31 age model is refined through inter-regional comparison of planktic foraminiferal ranges and δ^{13}C records from three other South-Tethyan localities (ODP Holes 762C and 763B, Exmouth Plateau, and the Guru section, Tibet). This age model enables correlation of the regressive events at a global scale and suggests that, within stratigraphic uncertainty, the TDP 31 depositional sequences are synchronous with the global Turonian third-order sequences and are likely driven by eustasy. These correlations, together with recent astrochronological and radiometric dating, indicate a considerably younger age (91.17 ± 0.52 Ma) for the top *H. helvetica* Zone than currently assumed, resulting in zonal duration of 2.35 ± 0.52 myr. Foraminiferal stable-isotope data from TDP 31 indicate slight surface- and bottom-water warming during the regressions and possibly a minor surface-water salinity decrease, which is inconsistent with glacio-eustatic forcing of Turonian third-order sea-level cycles and is more in line with the model of aquifer-eustasy.

1. Introduction

In the light of current climate change and melting polar ice sheets, attempts to understand better the complex processes and feedback mechanisms that influenced global sea level over geologic time have gained momentum in recent years. Despite many advances in sea-level research, the nature of cyclic eustatic sea-level fluctuations during past warm periods without, or with much reduced, polar ice remains enigmatic. Solid earth dynamics that are unrelated to glacial cycles can explain first and second order sea-level cycles (Conrad, 2013), but not the third-order cycles that are evident from sequence stratigraphy (Haq, 2014).

Looking from the perspective of an icehouse world, it is hard to envision processes other than the waxing and waning of ice sheets as the main driver of these third-order eustatic sea-level fluctuations. Even for the Cenomanian and Turonian, the warmest period of the Cretaceous greenhouse climate (e.g. Huber et al., 2002; Friedrich et al., 2012), operation of glacio-eustasy remains an ongoing controversy (Miller et al., 2003, 2004; Moriya et al., 2007; Bornemann et al., 2008; Ando et al., 2009; MacLeod et al., 2013). Some modeling results for the Late Cretaceous suggest the possibility of the build-up and decay of Antarctic ice sheets on time-scales of 20–80 kyr under certain boundary conditions (Flögel et al., 2011). However, while theoretically possible, sedimentological evidence for glacial episodes during the mid-Cretaceous is missing. Geochemical arguments for a short (~200 kyr) glacial period in the Middle Turonian (Bornemann et al., 2008), or for explanation of relatively long-term (myr-scale) regressive cycles during the Cenomanian to

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Coniacian (Galeotti et al., 2009), have been called into question (e.g. MacLeod et al., 2013; Uličný et al., 2014; Wendler and Wendler, in this volume). Although the existence of sporadic, short-duration glacial episodes may be possible under greenhouse climate conditions, they do not seem to offer a convincing explanation for the repeated/cyclic third-order eustatic sea-level fluctuations that are evident during the mid-Cretaceous.

If past warm greenhouse climate conditions did not allow for substantial amounts of water to accumulate on land in a solid state (as ice in the cryosphere), then the focus for an explanation of eustatic sea-level cycles during these periods should probably be shifted from the solid to the liquid aspect of the hydrological cycle. Such alternative concepts for eustatic sea-level change might involve steric effects (ocean water volume in relation to temperature) and groundwater storage. The latter concept was first proposed by Hay and Leslie (1990), but has been considered in very few studies (Jacobs and Sahagian, 1993) and is only recently gaining more attention (Föllmi, 2012; Wagreich et al., 2014; Wendler et al., 2014; Wendler and Wendler, in this volume; Wendler et al., 2011c; Wendler et al., in this volume).

Key to understanding the eustatic component in sea-level oscillations is evaluation and comparison of the timing and magnitude of reconstructed relative sea-level changes from individual sections. This approach requires sufficiently precise stratigraphic correlation and correct interpretation of paleobathymetric proxies. Traditionally, biostratigraphy forms the basis for correlating sedimentary sequences, and additional methods such as magnetostratigraphy, astrochronology, and chemostratigraphy are increasingly used to: (1) improve the resolution of age models, (2) test for biostratigraphic synchronicity of marker species, and (3) more precisely relate different biostratigraphic schemes (e.g. Laurin et al., 2015; Sageman et al., 2014; Voigt et al., 2012; Wendler, 2013).

The combination of these correlative methods, together with the increasing number of published high-resolution records (e.g. Uličný et al., 2014), and availability of new, well-preserved Cretaceous material, e.g. from the Fossillagerstätte in Tanzania (Wendler and Bown, 2013; Wendler et al., 2013a; Wendler et al., 2013b), offer new chances, as well as challenges, for research on understanding the drivers of past greenhouse world eustasy. A recent compilation of Late Cretaceous $\delta^{13}C_{carb}$ records and biostratigraphic and magnetostratigraphic data (Wendler, 2013) provides the means for global correlation at increased temporal resolution for this geologic period and confirms synchronicity for some of the foraminiferal marker species. The study also points out discrepancies (i.e. species occurrence diachroneity) that challenge traditional biostratigraphic concepts and that need to be solved in order to improve stratigraphic correlations. The exceptionally well-preserved microfossils recovered in the Cretaceous sediments from Tanzania onshore drilling provide unprecedented structural detail for taxonomic and biostratigraphic studies (Falzoni et al., 2013, 2014; Haynes et al., 2015; Huber and Petrizzo, 2014; Petrizzo et al., 2011; Wendler et al., 2011a; Wendler et al., 2013b), as well as minimal alteration of geochemical parameters for palaeoclimate proxy development (Wendler et al., 2013a) and for testing the greenhouse glacier hypothesis (MacLeod et al., 2013). The wealth of detail preserved in these sediments challenges existing taxonomic concepts and ideas of proxy interpretation and, at the same time, offers a great chance for refinement of these concepts.

The mid-Cretaceous "Super-Greenhouse" is perfectly suited for studies on greenhouse climate eustasy and is well-represented in the Tanzanian sediments. In the present paper we summarize sedimentological, geochemical, and microfossil data from a Turonian drill site from Tanzania (TDP 31) and discuss their interpretation in terms of local sea-level history and the possible relation to global sequence stratigraphic cycles. The study presents one of the few open marine sections that combine microfossil biozones with sequence stratigraphy and chemostratigraphic interpretation for the Turonian. Additionally, the presence of exceptionally well-preserved microfossils in these sediments allows comparison of patterns in stable isotope records, derived from translucent foraminifera, with the local sequence stratigraphic model. Grain-size and stable-isotope data from site TDP 31 are regionally compared to records from two other Turonian TDP sites (TDP 22 and TDP 36). For wider correlative purposes and for development of an age model for TDP 31, we also compare Turonian $\delta^{13}C$ records (bulk carbonate/bulk organic/foraminiferal) and stratigraphic ranges of planktic foraminiferal key species from four sections that were all located in the southern Tethys Ocean (Fig. 1), but on three different tectonic plates: site TDP 31 (Tanzania, Africa; new and published data), ODP Holes 762C and 763B (Exmouth Plateau, Australia; previously unpublished data), and Guru section (Tibet, Greater India; published data).

2. Materials and sampling

During the Tanzania Drilling Project (TDP), marine hemipelagic Cretaceous sediments were recovered at eighteen land-based drill sites near the Tanzanian coast during three field seasons from 2007 to 2009. Turonian sediments were cored in 10 of these sites, of which site TDP 31 (10°1′49.80″S, 39°38′44.00″E) yielded the longest and most complete Turonian succession. For an initial attempt of local lithostratigraphic correlation, we also present grain-size and geochemical data for sites TDP 22 and TDP 36. For details on the location of these three sites, regional geology, and on initial sedimentologic, biostratigraphic, and geochemical results (bulk sediment: wt% carbonate and TOC, $\delta^{13}C_{org}$, $\delta^{13}C_{carb}$, and $\delta^{18}O_{carb}$) see Jiménez Berrocoso et al. (2015, 2012, 2010).

Site TDP 31 recovered 64 cores from a 115-m thick Lower Turonian to Coniacian interval of clay-rich and carbonate-poor siltstone. The Lower and Middle Turonian sediments below ~42 m depth are dark gray, finely bedded to laminated with minor signs of bioturbation (i.e. pyritized burrows in washed samples). The Upper Turonian sediments above ~42 m depth are lighter greenish-gray and largely bioturbated, with thicker and less distinct bedding. Core photographs for TDP 31 are provided in Appendix 1A–F. Successions of 130 m and 110 m thickness of Lower and Middle Turonian carbonate-poor sandy siltstones to silty claystones were drilled at sites TDP 22 and TDP 36, respectively. The cores were photographed, described, and sampled on site. Color variations in the core photographs due to the varying position of the sun were electronically normalized using the color of a wooden ruler for reference. For core numbering and sample abbreviation format see Jiménez Berrocoso et al. (2010).

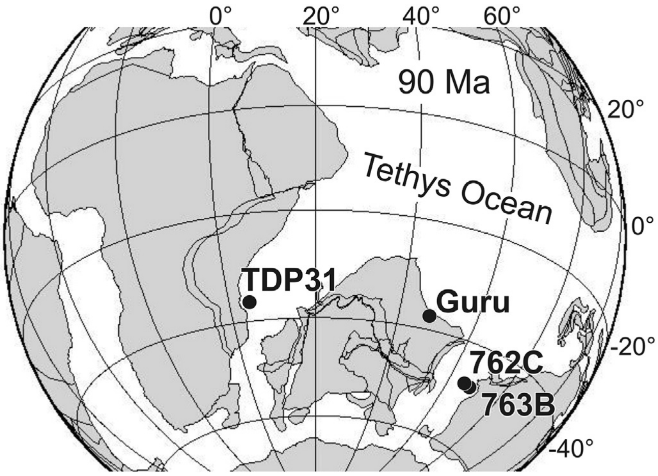

Fig. 1. Paleogeographic map for the late Turonian (~90 Ma) and the position of the four sections from the southern Tethys Ocean discussed in this study.

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