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Interactive comment on "Decline of coral reefs during late Paleocene to early Eocene globalwarming" *by* C. Scheibner and R. P. Speijer

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Reply on comments of two anonymous reviewers on "Decline of coral reefs during late Paleocene to early Eocene global warming" by C. Scheibner and R. P. Speijer:

First of all we would like to thank the two anonymous reviewers for their thorough reviews and their valuable comments. We are dealing in our paper with the decline of coral reefs during late Paleocene to early Eocene global warming. We are very much aware that this is a very complex topic that can not be discussed satisfactorily in full within the coverage of this journal due to the page and citation limit. Therefore we intended to highlight what we consider the key factor for the decline of coral reefs during the late Paleocene and early Eocene, i.e. the rising temperature. In another, expanded review paper (Scheibner and Speijer, subm.), we intensively discuss additional causal parameters (e.g. enhanced CO2 concentrations and varying trophic resource regimes.) for late Paleocene/earliest Eocene carbonate platform evolution in detail. We agree with the reviewers that these additional parameters work hand in hand with rising temperatures in this time interval. In the review paper we reveal the temporal and latitudinal evolution of Tethyan platforms for each individual area in detail and we discuss possible links between facies changes and the evolution of the main platform-building organisms (corals and larger foraminifers). Consequently, the purpose of the present paper is to provide a synopsis of our observations, interpretations and ideas in the succinct format of eEarth in order to reach a broad non-specialist public.

We are well aware that we are not the first to correlate the larger foraminiferal turnover with the carbon isotopic excursion (CIE) and we did not prefer to neglect the importance of the work of Orue-Etxebarria et al. (2002) and Pujalte et al. (2003) on the Pyrenees, one of the most important areas worldwide for Paleogene platforms. However, we have to stress here that page and citation (max 30) limitations have posed the problem of exclusion of some key references. Since we are addressing coral reefs rather than larger foraminifera, we feel justified in our decision not to include the above references here, in contrast to our earlier paper on the foraminiferal turnover (Scheibner et al. 2005).

In the following we will address the main points of criticism of the two referees.

1) Decline of modern reef ecosystems is multifunctional: In this paper we are concentrating on rising sea-surface temperature as the prime cause for the decline of the coral reefs in the late Paleocene to earliest Eocene. This scenario is certainly somewhat oversimplified, as pointed out by both referees. Other factors besides rising temperature undoubtedly contributed to the decline of coral reefs as well, but we believe that the rising temperature is the main overall cause for the changes in platform settings around the Paleocene/Eocene boundary. Therefore, and for the reasons pointed out above, we concentrated in this paper solely on the temperature effect, while in Scheibner and Speijer (subm.) the absolute and latitudinal changes of climate proxies (temperature, C02, precipitation) and the efforts of modeling early Paleogene climate

to reproduce the results of these proxies are discussed. Furthermore, in the review paper we present a short overview on the trophic resource regime (Hallock, 1987) in the oceans within that time interval. The variations within these climate proxies are among other things (variation of Mg/Ca ratios, evolutional trends within larger foraminifera) important to explain the distribution patterns of the major organism groups within the shallow-water realm during this time period, corals and larger foraminifera. The coral and larger-foraminifera distribution patterns in turn are responsible for the proposed three -step platform evolution and the latitudinal gradients of the platforms.

Corals are highly sensitive to their ambient water quality, particularly temperature, and are therefore considered excellent proxies for climatic change. In Scheibner and Speijer (subm.) we summarize the temperature sensitivity of corals, especially temperature changes connected to El-Nino Southern Oscillation events (ENSO). The importance of CO2 for calcification of corals is also discussed and finally the geochemical composition of seawater with respect to Mg and Ca is elaborated. All these parameters controlling recent coral or coral reef growth were strongly debated in recent years and for further information the reader is referred to specialized literature (e.g. Brown, 1997; Hoegh-Guldberg, 1999, 2005; Wilkinson, 1999; Kleypas et al., 2001; Fitt et al., 2001; Barton and Casey, 2005).

Similar to reef-building corals, larger foraminifera are sensitive to changes in water quality and thus record global changes in the shallow-water domain (Hallock, 2000). In Scheibner and Speijer (subm.) we look in detail into parameters controlling the life and evolution of larger foraminifera, i.e. their sensitivity to solar radiation, to variation of seawater chemistry and to nutrient supply. Furthermore, the concepts of K-strategy and global maturation cycles, both important for the general evolution of larger foraminifera, are recapitulated.

2) Stratigraphy: Both reviewers question the biostratigraphic accuracy of the shallow-benthic zonation of the different studies. The Paleocene/Eocene boundary in both deep-marine and shallow-marine settings can be reliably tied to the base of the nega-

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tive carbon isotopic excursion (CIE), displaying a shift of about 2-3 promille; (Aubry and Ouda, 2003; Luterbacher et al., 2004). Detailed investigations of the P/E-boundary interval in pelagic sediments refined the exact position of the carbon isotopic excursion to the boundary between zones P5 and E1 and NP9a and NP9b in the planktic foraminifera and calcareous nannofossils, respectively (Aubry, 1995; Berggren and Pearson, 2005). In the shallow benthic correlation scheme of Serra-Kiel et al. (1998) this level was thought to correlate with the boundary between SBZ5 and SBZ6. Another important event that occurred within the P/E transition is the Larger Foraminifera Turnover (LFT after Orue-Etxebarria et al., 2001) that was first described from the Pyrenees by Hottinger and Schaub (1960). The LFT is characterized by the start of adult dimorphism and large shell size in larger foraminifera, especially the nummulitids and alveolinids (Hottinger and Schaub, 1960; Hottinger, 1998), which correlates with the beginning of platform stage III. Recent investigations in Egypt demonstrated that the LFT and hence the boundary between SBZ4 and SBZ5 closely correlates with the CIE, marking platform stage III the base of the Eocene (Scheibner et al., 2005; Scheibner and Speijer, in press). This redefinition of the Paleocene/Eocene boundary in the shallow-water domain could have contributed to some sort of confusion, as the corresponding paper is still in press (Scheibner and Speijer, in press). The boundary of platform stage I to platform stage II correlates with the boundary of SBZ3 and SBZ4, which is certainly not as characteristic as the Paleocene/Eocene boundary between SBZ4 and SBZ5. But nevertheless all shallow benthic zonations are characterized by their characteristic species. Prior to the revision of the shallow-benthic foraminiferal biozonation (Serra-Kiel et al., 1998) SBZ3 was established by Hottinger (1960) as the G. primaeva Biozone, defined by the total range of G. primaeva. The precursor of SBZ4 was established by Hottinger (1960) as the G. levis Biozone, defined by the total range of Glomalveolina levis. Several index taxa are characteristic for SBZ4: Hottingerina lukasi, Glomalveolina spp., Miscellanea spp., Ranikothalia spp., Dictyokathina simplex, and Thomasella labyrintica. According to Hottinger (1960) the precursor biozones of SBZ5 and SBZ6 are the A. cucumiformis and A. ellipsoidalis Biozones, identified by the total ranges of A. cucumiformis (junior synonym of A. vredenburgi, Hottinger et al., 1998) and A. ellipsoidales, respectively. Larger foraminifera of this biozone are very easily recognized, because of the first appearance of true alveolinids, which are characterized by an increase in size, flosculinisation, axial thickening and adult dimorphism (Hottinger, 1960). We agree with the referees that at a first glance some of the cited papers do not follow the SBZ notation, which makes a direct comparison much more difficult, but a lot of the papers mention at least one or two of the index species and can be therefore transferred into the SBZ scheme. In most studies platform stage III can be easily recognized by the presence of the first true alveolinids and nummulites.

Referee 2 also points to an apparent discrepancy in the correlation of the base of SBZ4. He states that Scheibner et al. (2005) correlate the base of SBZ4 with a level just above the NP6-NP7 boundary, whereas in the Pyrenees the same level is usually constrained within the uppermost NP8. But this apparent discrepancy is the result of an uncertain correlation of shallow-water and deep-water stratigraphies in one section in Egypt, and is therefore marked with a dashed line in Scheibner et al. (2005).

3) Relevance of selected areas: Referee 2 questions the relevance of the selected areas. He states that only 3-4 areas, particularly the Pyrenees and Egypt, allow the identification of the three platform stages. We agree with referee 2 that especially in the Pyrenees and in Egypt the subdivision into three platform stages is straightforward, which was the reason why we established the concept of the platform stages in these areas. In all other areas this subdivision is not as obvious and maybe by looking at an individual area only such a subdivision would not be as straightforward. But if one compares all areas simultaneously this threefold platform stage pattern is eye-catching. In the following we present some of the less straightforward areas in detail to demonstrate the validity of our generalisations.

Ionian Islands: From the late Cretaceous to the early Eocene Accordi et al. (1998) established the following sedimentary model: Stage 1: Late Cretaceous orbitoid/rudist shoal-dominated rimmed shelf. Stage 2: Paleocene (up to SBZ3/SBZ4) coral/algal sandy blanked-dominated ramp. SBZ3 and SBZ4 are not separated, but all facies associations containing corals were attributed to both biozones, suggesting coral growth up to the P/E boundary. At the same time larger foraminifera dominated facies were deposited in the peritidal and middle to outer ramp environments. Stage 3: Early Eocene (SBZ5/SBZ6) larger foraminiferal shoal-dominated ramp with additionally remains of bivalves, gastropods, echinoids, red algae and colonial corals.

Oman: Racz (1979) investigated the Paleocene carbonates of the Umm er Radhuma Formation in Oman, although the mentioned larger foraminifera (true alveolinids and nummulitids) suggest a stratigraphic range of at least Paleocene to early Eocene. The three mentioned biostratigraphic units Daviesinea Zone, Miscellanea-Distichoplax Zone and Nummulites-Alveolina Zone can be roughly assigned to SBZ3, SBZ4 and early Eocene, respectively. Calcareous algae and larger foraminifera are the prominent fossil components, while coral, gastropod and brachiopod fragments occur only locally (Racz, 1979). The "reef" facies in the investigated interval is composed of oncoids, constructed mainly by red algae, predominantly Ethelia alba. Summarizing it can be said that coral reefs were absent in the Paleocene of Oman, potentially replaced by oncoids, while larger foraminifera dominated the late Paleocene to early Eocene.

Tibet: In Tibet, the upper Paleocene is characterized by Miscellanea spp., Ranikothalia spp., Discocyclina spp. and other rotaliids while the Ilerdian is dominated by Alveolina spp. Opertorbitolites spp., Orbitolites spp. and Nummulites spp. Fragments and completely preserved solitary and colonial corals only occur subordinately in the first two members of the upper Tibetan Paleocene/lower Eocene Zhepure Shan Formation. The Zhepure Shan Formation starts in the middle Paleocene (M. angulata zone/P3) and members 1 and 2 can be roughly compared to SBZ2 and SBZ3. However, larger coral reef complexes, dominantly composed of corals are not encountered (Wan et al., 2002; Zhou et al., 1997; Willems, 1993; Willems and Zhang, 1993a, b; Willems et al., 1996).

NW-Somalia: Carbone et al. (1993) analyzed the Paleocene-lower Eocene carbonates of the Auradu Limestone Formation in NW Somalia, which is characterized by larger foraminifera (Lockartia spp., Sakesaria spp., Miscellanea spp., Alveolina spp., Nummulites spp.) associated with dasycladalean algae, corals, mollusks, bryozoans, brachiopods, and echinoids. The majority of the studied coral colonies have been collected from the lower part of the Auradu Formation, suggesting a Thanetian age. A more precise age assignment, however, is not possible, i.e. it is not clear whether the coral colonies are restricted to SBZ3 or thrived up to SBZ4 .

4) larger foraminifera and solar irradiance: Referee 1 is absolutely right with the comment that larger foraminifers are affected equally to corals by solar irradiance (Hallock, 2005) but in contrast to reef-building corals, in which the symbionts are sensitive to slight increases in summer sea-surface temperature, symbiont loss or bleaching in larger foraminifera (Amphistegina) shows no correlation to summer temperature (Hallock, 2000, 2005; Hallock et al., 2006). Bleaching in larger foraminifera is therefore rather related to increased solar radiation, indicating that larger foraminifera are living close to their threshold for this particular stress factor (Hallock, 2005).

5) larger foraminiferes and symbionts: Referee 1 questions the actualistic model that Paleogene larger foraminifers host symbionts. According to literature the construction of these extreme large tests by single-celled organisms is only possible through symbiosis with photosynthetic algae. During evolution the tests of larger foraminifera tend to get more complex and larger to evolve to almost perfect "greenhouses" for their symbiontic algae (Lee et al., 1979; Hallock, 1988).

6) larger foraminifera abundance in the lower Eocene: Referee 1 states that we compare the abundance of larger foraminifera in the lower Eocene with situation of today. This is not correct. The situation of today can be only compared with platform stage I or possibly platform stage II. The point we intended to stress is that if the general warming trend would continue than it could be possible that larger foraminifers again are going to play a similar prominent role on warm water carbonate platforms comparable to the Early Eocene times.

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