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Climate of the Past Discussions

Interactive comment on "Cyclone trends constrain monsoon variability during Late Oligocene sea level highstands (Kachchh Basin, NW India)" *by* M. Reuter et al.

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First at all we welcome the openness of referee 1 for sound sedimentological reasoning. The referee expresses grave reservation about the origin and palaeoenvironmental interpretation of the shell beds as well as the sequence stratigraphic correlations. In particular, he challenged the possibility of sediment transport from deep to shallow water. Storm process and effect, however, change tremendously with the kind of sediments, the pysiographic setting, and water depth (Seilacher and Aigner, 1991). Gagan et al. (1990) describe processes of sediment reworking in deep water and redeposition in shallow water during cyclone Winifred, which is in accordance with our

depositional model of deep to shallow water sediment transport. The authors indicate that strong wave oscillation currents resuspended mid-shelf sediment and combined with unidirectional wind-forced currents to transport sediment toward shore and along shelf. Possibly, the low density skeletons (echinoderms, larger benthic foraminifers) and/or flattened shape (larger benthic foraminifers, Amussiopecten) of the predominant deep water components in the shell beds caused a high transport capacity (Nebelsick and Kroh, 2002) despite of a large grain size. This may explain the low diversity of the skeletal assemblages in the shell beds. Accordingly, calculated threshold shear velocities for large-sized Nummulites confirm that the larger benthic foraminifers can be easily moved by weak wave-driven currents (Jorry et al., 2006). Notably, it has been assumed that the erosion of sediments in relatively deep water and their deposition in shallower water under the influence of storms may have produced inverted depositional sequences and allochthonous foraminifers in sediments along the recent coast of Kachchh (Nigam and Chaturvedi, 2006). In his review, referee 1 had not considered the presented palaeontological evidence for shell accumulation in a shallow setting. The surfaces of the shell beds are frequently encrusted by large colonies of zooxanthellate corals or penetrated by Kuphus tubes. The presence of these organisms clearly indicates shell bed deposition in a very shallow inner ramp setting. Importantly the corals as well as Kuphus bivalves are preserved in life position and therefore cannot have been supplied from shallower source areas. The micrite-rich sediments, which separate the shells beds and represent the normal (background) sedimentation, contain only shallow marine faunas (reef corals, mollusks, foraminifers, ostracods) while planktic (evidence for deeper, open marine conditions) and deeper water biota are not observed. Along with these biotic evidences, the occurrences of early diagenetic dolomite point to restricted shallow-marine conditions. Accordingly, ferruginous crusts and ferriclastic deposits, which occur associated with the dolomite, are interpreted to document pedogenesis during emergence episodes. In contrast, the referee noted that ferruginous crusts should be strictly interpreted to represent marine drowning under sediment starvation, not as surfaces related to emergence and atmospheric exposure. Autochthonous lateritic soils as well as their reworked products are, however, well known from the Cenozoic succession of Kachchh (e.g. Biswas 1992; Valeton and Wilke, 1993; Valeton 1999) and larger ferriclasts from the studied section typically represent nodules or fragments of nodules with pedorelics suggesting a laterite origin. Comparable laterite nodules are pictured by Santos et al. (2004). Associated mammal bones support the interpretation of a terrestrial origin (if necessary we can provide photographs). The thin autochthonous iron crusts are interpreted as relics of reworked laterite soils because they either occur in association with ferriclastic sediment and/or early diagenetic dolomite indicating reworking of terrestrial soils and a restricted marine environment before and after an emergence episode (Figs. 2, 3). Therefore the standard sequence stratigraphic interpretation, which is preferred by the referee and places the ferruginous crusts immediately below maximum flooding surfaces, is unlikely.

The concept of the recognition of eustasy as a mechanism for driving stratigraphic sequences has been vigorously debated in the Geologic Time Scale 2012 (see Simmons 2012 for review). In the GTS 2012, sequence stratigraphy has been summarized as an attempt to subdivide sedimentary successions (at a variety of scales) into packages relating to changes of relative sea level. Relative sea-level changes are driven by a combination of eustasy, tectonics and sediment supply. Although it has been argued in recent years that many third order, small scale, sea-level changes can be explained by variations in local crustal uplift and subsidence and that magmatic underplating of the crust can cause relatively rapid and high frequency regional sea-level changes, the GTS 2012 makes clear that this rules not out the possibility of a genuine eustatic signature and there exist emerging evidence for the synchronicity of sequence stratigraphic surfaces (Simmons, 2012). According to the GTS 2012, the concepts of sequence stratigraphy can be applied independent of the data type. Wells and outcrops can be interpreted in terms of their observed or implied vertical facies successions and then correlated using biostratigraphy. Such correlations mimic the geometries visible in seismic data and it is readily possible to make regional interpretations using only outcrops

and wells (Simmons, 2012). A major problem of the stratigraphic correlation of shallow water carbonate successions is the poor biostratigraphy and stratigraphically incomplete record, compared to deep water successions. It is therefore necessary to use an integrated approch to refine the age model. Although the eustatic signal may have been modified by local and regional tectonics (chapter 5.3 Effects of sea level and tectonic uplift on sedimentation) and climate in the studied sedimentary succession, our sequence stratigraphic correlation is consistent with independent stratigraphic methods (biostratigraphy) indicating a genuine eustatic signature.

An event bed is inherently erosive at its base and will therefore destroy and incorporate previous background and event deposits. The degree of cannibalism will generally increase in a proximal direction and depends on the overall rate of sedimentation and subsidence (Seilacher and Aigner, 1991). Therefore, counting of proximal tempestite beds like in Maniyara Fort Formation is not appropriate to calculate storm interval durations. But even if an event bed represents multiple-event accumulations, the distribution pattern of the typical skeletal assemblages in the studied section displays systematic changes in storm deposition. Due to the properties of the stereom, the echinoderm skeleton is very durable during life, but is easily abraded and transported after death (Chave, 1964). Immediate burial is therefore essentially for good preservation of articulated or lightly skeletonized specimens, such as irregular echinoids (Kidwell, 1991). The, mass occurrences of irregular echinoids therefore contradict a (para)sequence stratigraphic interpretation of the shell beds.

We are aware, that the presented section cannot be used as constraint for storm activity and wave base depth over maxima and minima of a full climatic cycle. Therefore, we choose the title “Cyclone trends constrain monsoon variability during Late Oligocene sea level highstands (Kachchh Basin, NW India)” for this work and don’t attempt to reconstruct climate variability over a full climatic cycle. However, despite of its incomplete sedimentary record, we think the section is suited to quantify long-term (c. 4.5 Ma) atmospheric changes. This is possible because we only consider the climatic conditions during highstands and don't mix them up with the different climatic condition of a lowstand. The results are important because they represent the first direct proxy data for atmospheric dynamics over the Eastern Tethys, which was a key area for the development of the Asian monsoon climate during the Oligocene–Miocene transition.

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