Geophysical Research Abstracts,
Vol. 10, EGU2008-A-09539, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-09539
EGU General Assembly 2008
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Ice in the middle Cretaceous to early Paleogene greenhouse: a continuing paradox

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During the middle Cretaceous to Paleogene the earth experienced a period of global warmth, commonly coined the greenhouse earth. This climate state is characterized by high polar temperatures, low latitudinal temperature gradients, and sluggish oceanic, possibly halothermal circulation. Therefore most scientists believe that continental glaciation could not take place under these climatic conditions, an opinion that has been questioned during the last years based on various lines of evidence. Specifically, high amplitude, rapid sea-level changes during this greenhouse period can only be explained by invoking glacio-eustasy, furthermore numerous bulk-rock oxygen isotope records show positive inflections similar to those known from the Quaternary. Most recently, a study based on excellently preserved foraminiferal carbonate made a good case for such a hothouse glaciation for the middle Turonian (Bornemann et al., 2008, Science). This event coevals with sea-level changes of a magnitude between 25 to 40 m as recorded in sediments from the New Jersey Margin and the tectonically stable Russian Platform. Another time interval in which waxing and waning of polar ice volume is least expected is the transient rapid warming event at the Paleocene-Eocene transition, the Paleocene-Eocene thermal maximum (PETM). Yet, micropaleontologic and sedimentologic studies in the Nile Basin (Egypt) on the African northern margin revealed a sea-level fall of some 15-20 m immediately prior to the PETM, followed by a rapid rise of comparable magnitude during the early PETM. Similar patterns are also observed in another North African sequence in Tunisia. In addition, other passive

margin sequences in New Jersey, Central Asia, New Zealand and the Arctic Sea indicate that the PETM is associated with sea-level rise and/or transgression, in some cases after a sea-level fall just prior to the PETM. Deep-sea warming would lead to thermal expansion of the oceanic water column and could explain a sea-level rise of 4-8 m at most. Therefore, the remaining magnitude of sea-level rise must result from melting ice, possibly stored in high-altitude ice covers or in polar ice caps. Our observations are in agreement with the proposition by Miller et al. (2005, Science) who argued that during the late Cretaceous to early Eocene greenhouse period the central parts of Antarctica must have had a restricted ice cap. The waxing and waning of such an ice cap could have been sufficient to explain the amplitude of the sea-level fluctuation associated with the PETM as well as the isotopic patterns observed in the recent study for the Turonian. In conclusion, it appears that either the climate models of a greenhouse world or the interpretation of sea-level fluctuations and stable isotope data are fundamentally flawed. In order to overcome this paradox, there is a continued need for high-resolution multiproxy studies on stratigraphically well-calibrated sequences in order to identify synchronicity of sea-level cycles and isotopic excursions as well as for improved numerical modeling to test the hypothesis of hothouse glaciations.