AN ATLANTIC JACUZZI IN THE CRETACEOUS

Astrid Forster, Stefan Schouten and Jaap S. Sinninghe Damsté*

Future atmospheric levels of carbon dioxide are anticipated to rise substantially during this century. Since carbon dioxide is an important greenhouse gas, this is expected to result in a warmer climate but it is not easy to predict how warm. In the geological past, such as in the mid Cretaceous (80-120 My ago) there have been times characterized by atmospheric carbon dioxide levels 4-10 times higher than pre-industrial levels. Using a palaeothermometer called TEX_{86} based on fossil membrane lipids of archaea, we estimated tropical sea surface temperatures (SSTs) in the mid-Cretaceous. The results show that tropical SSTs varied between 30 and 40°C, suggesting substantially warmer oceans in the near future.

In the last years we have developed a method to reconstruct SST by the analysis of fossil membrane lipids of pelagic crenarchaeota, tiny prokaryotic organisms which occur ubiquitously in the ocean. These archaea adjust their membrane composition according to temperature and a small amount of these lipids escapes mineralization and is stored in marine sediments. In this way, marine sediments function as archives of past climate change and can provide information on extreme climates in the past.

Calibration of the thermometer for high temperatures

One problem in the application of this palaeothermometer is that it is calibrated for present ocean systems, where annual mean SSTs are always <30°C (TEX_{86}<0.7). Consequently, TEX_{86} values >0.7 have to be extrapolated from the present-day core-top calibration curve. To overcome this problem, waters from the tropical Indian Ocean containing Crenarchaeota were incubated in mesocosms at temperatures ranging from 25 to 40°C (Fig. 1) to study the changes in membrane lipid composition. Our results reveal that Crenarchaeota were able to thrive at temperatures up to 40°C and show a similar linear correlation of TEX_{86} with incubation temperature as demonstrated previously for incubation experiments at lower temperatures (Fig. 2). However, due to changes in the membrane lipid composition that are not observed for fossil lipids in sediments deposited in exceptionally warm oceans of the geological past, our mesocosm calibration should still be used with caution to convert TEX_{86} values from these sediments into SST.

Fig. 1. Set-up of the mesocosm experiments to calibrate the TEX86 at 30-40°C using waters from around the Seychelles. Experiments were carried out in the dark.

(*Corresponding author: damste@nioz.nl)

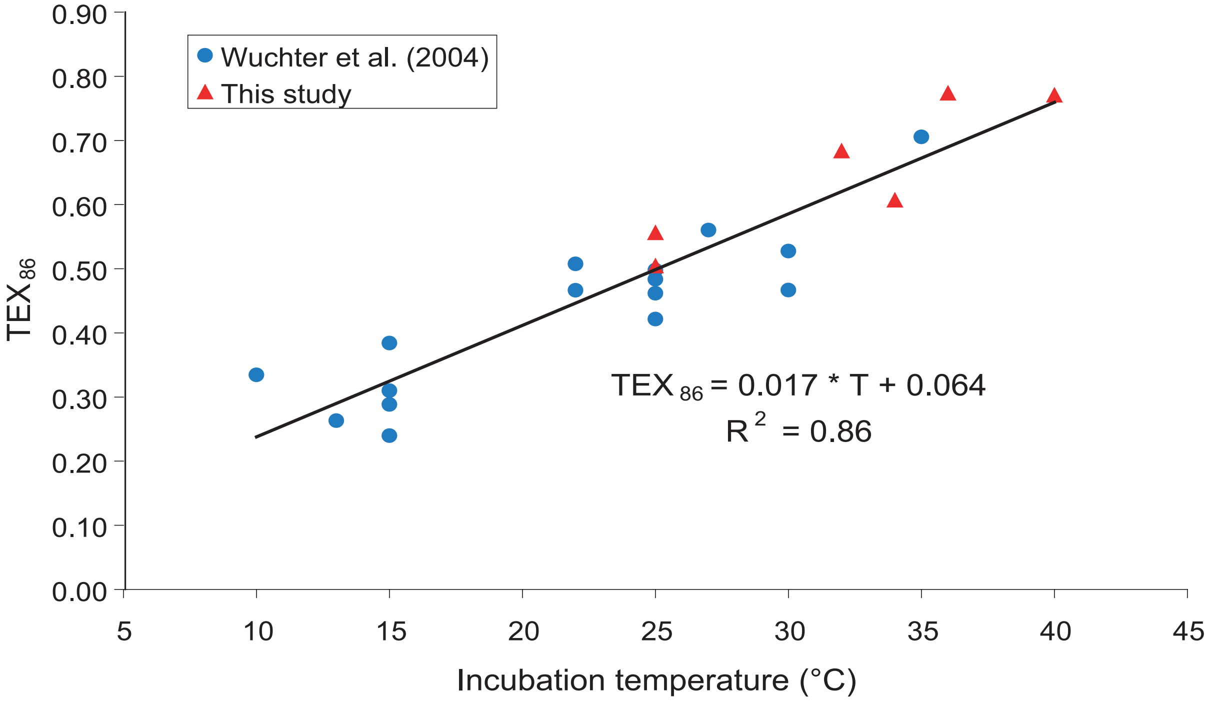

Fig. 2. Correlation of the TEX86 with sea water temperature in the mesocosm experiments. The blue points were obtained previously by Cornelia Wuchter using water from the North Sea. The data points in red were generated during this project.

Fig. 3. Part of the scientific party of Leg 207 to the Demerara Rise on the bridge of the ODP drilling ship the R/V Glomar Challenge. On the left Astrid Forster who was one of the organic geochemists participating on this expedition.

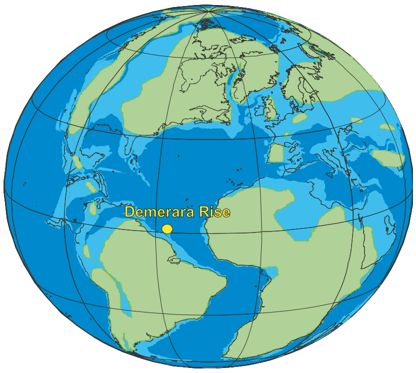

Fig. 4. Paleogeographic map of the Mid Cretaceous with the location in the tropical proto-North Atlantic Ocean of the drilling sites at the Demerara Rise (ODP Leg 207). Green=land, light blue= shallow sea, dark blue=deep sea.

Determining SSTs of the tropical ocean in a Greenhouse world

During the mid-Cretaceous (Early Albian to Campanian), Earth witnessed an extraordinarily warm climate and high sea-level. If mid-Cretaceous global warmth were linked to atmospheric carbon dioxide concentrations exceeding considerably the present level, contemporaneous SSTs should have been warmer than today globally, even in the tropics. We tested this by generating long-term TEX_{86} -based SST records on cores obtained during Ocean Drilling Program (ODP) Leg 207 (Fig. 3) to the Demerara Rise (western equatorial Atlantic, Fig. 4). We find that Albian-Santonian SSTs in the equatorial Atlantic Ocean (≥32°C) were substantially warmer than today (~27-29°C) with an optimum during the Turonian (Fig. 5). If we apply the TEX_{86} calibration from the mesocosm experiments (Fig. 2), reconstructed SSTs are even above 40°C (red scale Fig. 5).

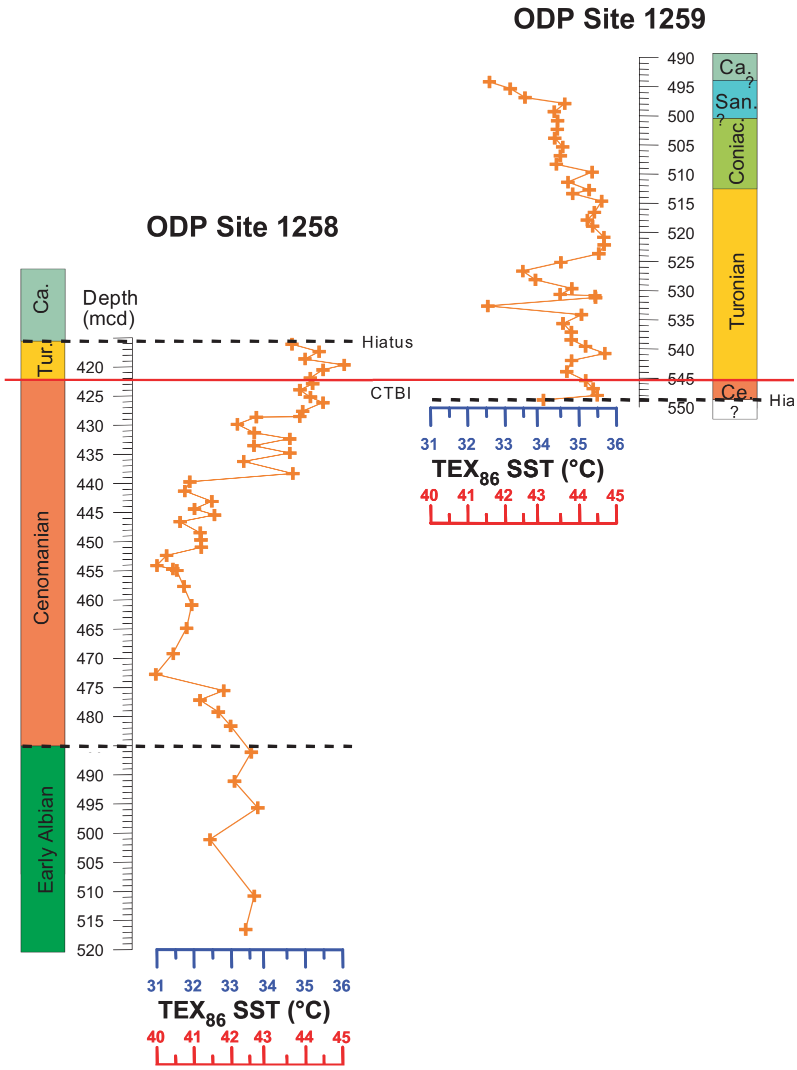

Fig. 5. TEX_{86} palaeo-SST records of Sites 1258 and 1259 revealing the long term trend from the Albian to the Santonian. The temperature scale in blue refers to the conservative estimate based on the present-day marine core top calibration (from Schouten et al., Geology 31 (2003) 1069-1072). The temperature scale in red is based on the TEX_{86}-temperature calibration of the mesocosm experiments (see Fig. 2). mcd = meters composite depth; Ca. = Campanian; Coniac. = Coniacian; San. = Santonian

These results are consistent with the hypotheses that the mid-Cretaceous high levels of atmospheric carbon dioxide were an important factor for the extreme warmth during this period. They also suggest that with increasing levels of carbon dioxide not only the poles but also the tropics will experience a substantial warming in the near future.