Lake Messel, a high resolution archive for early Middle Eocene climate variability

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The Middle Eocene oil shale of the Messel pit near Darmstadt (Hesse, Germany) is worldwide known for an exceptionally well preserved fossil assemblage. A continuous core from the center of the basin proved that the oil shale was deposited in a meromictic maar lake which formed due to a phreatomagmatic eruption 47.8 ± 0.2 Ma ago. The core included a complete reference section of the Middle Eocene lake deposits (Messel Formation) thus representing a unique climate archive for the early Middle Eocene in Central Europe.

The classical "Messel oil-shale" of the Middle Messel Formation is characterized by a continuous succession of finely laminated bituminous claystones, representing long-term stable meromictic conditions. They show a very fine light and dark lamination, which was caused by annual algal blooms of the coccal green alga *Tetraedron minimum* forming light spring and summer layers that were superimposed on the terrigenous background sedimentation, as represented by the dark autumn and winter layers. An average sedimentation rate of 0.14 mm/yr has been calculated from the lamination, but there are short-term fluctuations in varve thickness which can be attributed to an "Eocene ENSO".

High resolution palynological analysis of the oil shale of the Middle Messel Formation in the core, which represents a time interval of about 640 kyr, now provides an insight into the dynamics of a paratropical climax vegetation during the Middle Eocene greenhouse climate. Pollen and spores show that the vegetation surrounding Lake Messel did not change substantially in qualitative composition, but a change from a more humid climate with relatively high water levels in the lake to less humid conditions and lower water levels may be reflected by changes in the quantitative composition of the assemblage towards the top of the section. In addition to these long-term changes in the vegetation, short-term fluctuations in the frequency of individual taxa and certain clusters of taxa are recognizable.

Accepting an annual lamination, time series analyses of palynological data suggest that pollen assemblages reflect periodicities within the range of eccentricity, obliquity, long precession and short precession. This implies that orbital control of climate change was sufficient to impose quantitative changes in the composition of the terrestrial vegetation in the area though no taxonomic turnover occurred.

According to the cyclicity of the palynological data and with the availability of the astronomical solutions of La2004 and Va2003, it is now possible to implement an astronomical tuning to the 640 kyr record of the Middle Messel Formation. When tuning the pollen data to the La2004 Earth's orbital solution, the age of the Middle Messel Formation can be astronomically fixed between 46.6 and 47.3 Ma.