Interannual- to orbital-scale terrestrial paleoclimatic change during the early/middle Eocene Transition (EMET): evidence from annually laminated lacustrine deposits of the Green River Formation, northeastern Utah, USA

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Climatic oscillations on multidecadal- to millennial- timescales are widely recognized in the Holocene and last glacial paleoclimatic records. Given the marked correlation with cosmogenic radionuclide production rates, changes in solar activity are proposed to cause the observed climatic oscillations (e.g., ~11-year Schwabe cycle, ~88–110-year Gleissberg cycle, ~210-year de Vries cycle, ~1000-year Eddy cycle, and ~2300-year Hallstatt cycle; e.g., Grey, 2010; Steinhilber *et al.*, 2012; Adolphi *et al.*, 2014). Evidence of a ~1500-year climate cycle is also reported mainly from North Atlantic and Arctic records (i.e., Bond events in the Holocene and Dansgaad-Oeschger cycles (DOC) in the last glacial), which likely linked to internal climate variability (e.g., Bond *et al.*, 2001; Barker *et al.*, 2011; Darby *et al.*, 2012; Kawamura *et al.*, 2017). However, studies of decadal- to millennial-scale climatic variations are rare for time intervals prior to the Pleistocene, except for some record (Kern *et al.*, 2012; Lenz *et al.*, 2017; Ma *et al.*, 2022), essentially due to the lack of appropriate datasets based on reliable proxy and archives. Recently, Hasegawa et al. (2022) analyzed the annually laminated lacustrine deposits (Shinekhudag Fm) in southeast Mongolia and demonstrated the occurrence of decadal–centennial-scale solar-linked variation and millennial-scale abrupt oscillations during the late Early Cretaceous. The results suggest that millennial-scale climatic changes similar to the last glacial DOC may also have occurred during the Cretaceous “greenhouse” period. In this study, we reconstruct decadal- to orbital-scale climatic variability at the interval of the early/middle Eocene Transition (EMET) by analyzing the annually laminated lacustrine deposits of the Green River Formation in Utah, USA, in order to verify millennial-scale climate stability during the same period.

The sample used in this study is a P4 core (ca. 70 m) drilled in northeastern Utah, which is thought to be deposited between 49.02 and 48.37 Ma based on the radiometric age of the intercalated tuff (Smith et al., 2010; Whiteside & van Keuren, 2009). The core consists of alternating layers of well-laminated shale and weakly-laminated dolomite. Elemental composition analysis was performed using XRF core scanner (Itrax) at the Lamont Earth Institute. The eCOCO analysis constructed by Li et al. (2018) was then performed on the obtained elemental compositional variations, and converted to time series data through a cyclostratigraphic analysis. We also analyzed interannual- to decadal-scale variations using fluorescence microscopy and lamination-scale elemental composition analysis by EPMA. The results reveal that proxy of summer algal productivity and Mn/Fe ratio (proxy of lake bottom redox condition) showed pronounced 11 years and 80-90 years cycles, which correspond to well-documented solar activity cycle (the Schwabe and Gleissberg cycles described above). Furthermore, Ca/Ti (proxy of evaporation/precipitation change) and Mn/Fe (proxy of lake bottom redox condition) obtained by Itrax analysis revealed a marked periodicity of 40-kyrs obliquity cycle and 400-kyrs eccentricity cycle, suggesting that paleoenvironmental changes in the Green River Formation are influenced by mid- to high latitudes. On the other hand, millennial-scale variability is less predominant compared with the orbital-scale variability, which likely reflected the relatively stable mode of ocean ventilation during the EMET interval.

Keywords: Eocene, Greenhouse, Climate system, Solar-linked climate variations, Millennial-scale, Climate stability