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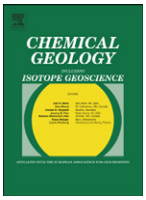

A high resolution study of trace elements and stable isotopes in oyster shells to estimate Central Asian Middle Eocene seasonality

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ABSTRACT

Modern Asian climate is characterized by strong seasonality caused by the duality between monsoon-dominated conditions in southeastern Asia and semi-arid to arid conditions in Central Asia. Eocene high-resolution proxy records which enable the reconstruction of the onset and magnitude of changes in seasonality are lacking to understand in details how and when this climatic turnover pattern occurred. Here, we propose an original method to estimate inter- and intra-annual variabilities in seawater temperature and salinity recorded by carbonate shell growth increments of the fossil oyster *Sokolowia buhsii* (Grewingk) collected from Late Lutetian marine strata of the Proto-Paratethys in the southwestern Tarim Basin (western China). Elemental ratio (Mg/Ca, Mn/Ca) and carbonate stable isotope composition ($\delta^{18}O$) were determined perpendicular to the growth lines of foliated calcite accumulated in the ligamental area during the oyster's lifetime. We use temperature dependant Mg incorporation to estimate seasonal temperature contrast in the past. Results suggest a warm annual average temperature (~27–28 °C) with large offset between summer and winter temperatures (until $\Delta T \simeq 19$ °C). Combining these temperature estimates with stable oxygen isotope analyses from the same growth increments we deconvolve seawater $\delta^{18}O_{sw}$ as a proxy for salinity. This suggests an average annual salinity about ~34–35 increasing strongly during summer months and decreasing in winter. Based on these data we conclude that during the Middle Eocene, Central Asian climate was characterized by a strong intra-seasonal variability in both temperature and salinity. Although the subtidal setting might have contributed to the strong seasonal offsets this still suggests that semi-arid to arid conditions prevailed during summer, whereas winter was characterized by enhanced rainfall. These results are consistent with previous regional palaeoenvironmental data and climate modelling experiments. They thus attest for the reliability of the method developed here as a seasonal palaeoclimatic indicator.

1. Introduction

The modern Asian climate is characterized by a strong contrast between the wet conditions in southeastern Asia in summer and the year round semi-arid to arid conditions in Central Asia. This contrast is the result of the Asian monsoon system with strong rainfall during the summer months in southeastern Asia and seasonally reversing winds (Molnar et al., 2010; Allen and Armstrong, 2012). The strong seasonality and the climatic contrast between southeastern and Central Asia climates are caused by the strong thermal contrast between the Asian continent and adjacent oceans (see Huber and Goldner, 2011 for a review). Based on climate modelling, this pattern is thought to have been established mainly by a combination of three main processes: (1) retreat of the Paratethys, an epicontinental sea formerly covering part of Central Asia (Ramstein et al., 1997; Fluteau et al., 1999; Zhang et al., 2007b); (2) uplift of Tibetan Plateau (Hahn and Manabe, 1975; Prell and Kutzbach, 1992; Boos and Kuang, 2010) both increasing the land–sea thermal contrast; and (3) South China sea expansion increasing water vapor content over the southeastern part of the continent (Zhang et al., 2007a). Numerous field studies showed the influence of the Tibetan plateau uplift on monsoon intensification during the Early Miocene (~23–20 Ma) to Late Miocene (~11–8 Ma) (Molnar et al., 1993; Clift et al., 2008; Molnar et al., 2010; Allen and Armstrong, 2012). However, the age of the initial uplift of the Tibetan Plateau as well as that of the Paratethys sea retreat have been significantly revised in recent years. High topography over large portions of the Tibetan Plateau is now known to be present at least from Eocene times onward (e.g. Dupont-Nivet et al., 2008; Wang et al., 2008; Van Der Beek et al., 2009; Quade et al., 2011) and is probably even older (Clark et al., 2010; Rohrmann et al., 2012). The Paratethys sea retreat was recently

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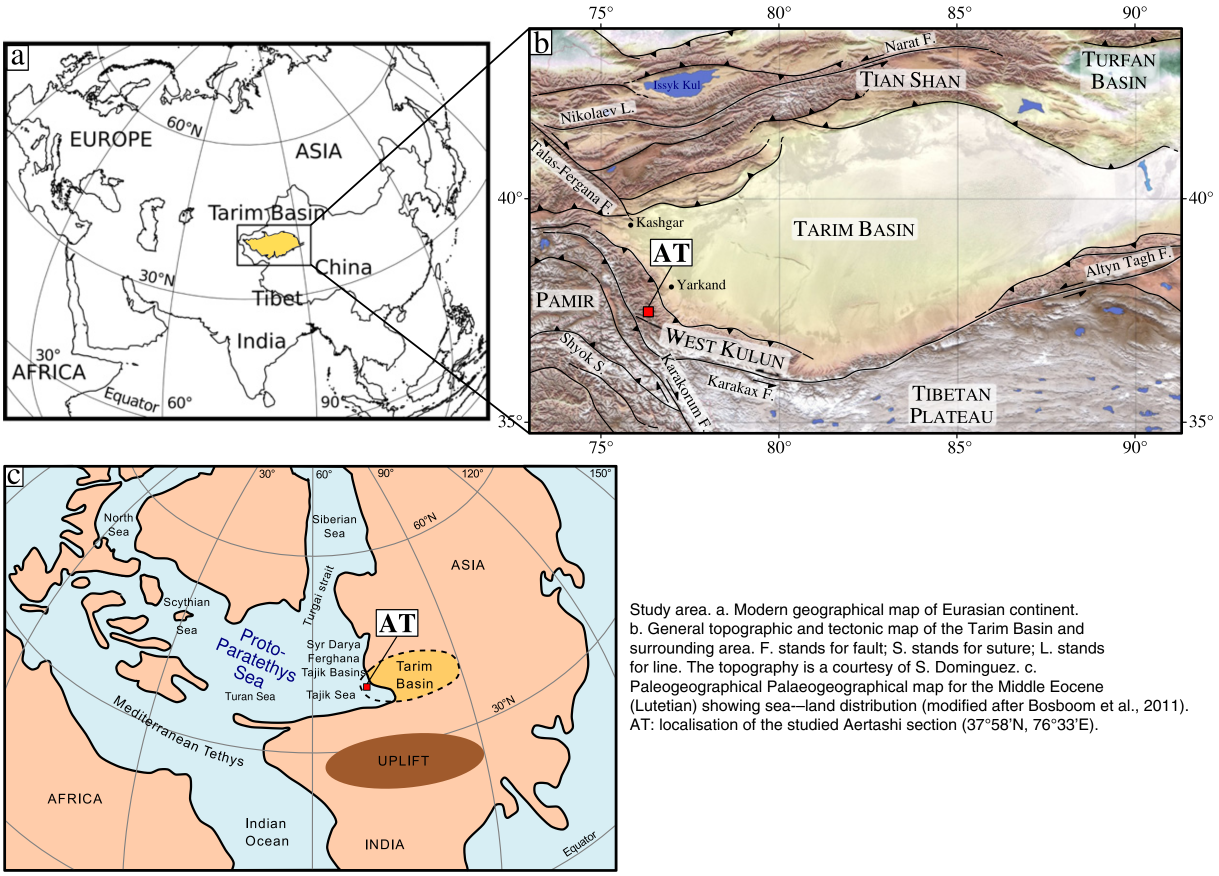
estimated to have started around 41 Ma (Late Lutetian) in the Tarim Basin (Xinjiang, Western China) followed by a final Late Eocene regression (38.5–35 Ma) after which the sea permanently disappeared from Central Asia (Bosboom et al., 2011, in press).

To test the validity of climate models and ultimately understand establishment and driving mechanism(s) of the monsoonal system, climate proxies are still lacking in the key Eocene period when these events are assumed to take place. Most of the investigations extend only back to Late Oligocene to Early Miocene ages (e.g. Spicer et al., 2003; Garzione et al., 2005). However sparse results from the Xining Basin in northeastern Tibet indicate progressive, stepwise aridification during the Eocene, culminating at the Eocene–Oligocene transition (Dupont-Nivet et al., 2007; Abels et al., 2010; Xiao et al., 2010) coinciding with humid conditions in coastal area (Sun and Wang, 2005; Hoorn et al., 2012). Of particular interest are recent palynologic constraints suggesting increased mid-Eocene seasonality (Quan et al., 2012) in the coastal areas suggestively linked to monsoon intensification. Our study focuses on the epicontinental sea formerly covering Central Asia which was isolated as the Paratethys sea during the latest Eocene or early Oligocene (Dercourt et al., 1993). Therefore, we will further refer to the mid-Eocene sea as the "Proto-Paratethys" (Fig. 1).

To understand climate variations during this key period in Central Asia, models need to estimate sea surface temperature (SST) to integrate the ocean-buffer behaviour of the Proto-Paratethys. Ramstein et al. (1997) assumed that the modern Caspian Sea can serve as an analogue for the Paratethys with respect to temperature and salinity. However, Zhang et al. (2007b) noted that SSTs are poorly constrained for the Eocene and hence used SST data of the Middle Pliocene from Dowsett et al. (1999) as boundary conditions for their Eocene climate model. Despite different initial assumptions these models converge in that they all show overall Central Asian aridification in response to a retreat of the sea and at the same time intensified monsoon. The absence of accurate SST reconstructions, however, makes it difficult to validate these models and hence understand the driving forces behind the development of the Asian monsoon. A major challenge for our study is to develop an approach to describe and potentially quantify the seasonal variations of temperature and salinity (reflecting the precipitation/evaporation balance) in the Proto-Paratethys sea environment.

The development of sclerogeochemistry on present and fossil bivalves (Klein et al., 1996; Kirby, 2000; Freitas et al., 2005; Batenburg et al., 2011) demonstrates that the elemental and stable isotopic composition of calcite from incremental growth rings allows recovering high-resolution quantitative palaeoclimatic signal. Specifically, oyster shells are built of low-magnesium calcite which is the most resistant calcium carbonate to alteration, resulting in many very well preserved fossils. Furthermore, oysters live in widely different ecosystem, tolerating salinity fluctuations, and are present in large stratigraphic, geographic and latitudinal distributions (Mouchi et al., 2013). For all these reasons, numerous studies have focused on present and fossil oysters to infer infra-annual (palaeo)climate (Surge et al., 2001; Surge and Lohmann, 2008; Lartaud et al., 2010; Titschack et al., 2010; Ullmann et al., 2010; Fan et al., 2011; Mouchi et al., 2013). Here we use fossil oyster shells (*Sokolowia buhsii*, Grewingk) recovered from Late Lutetian marine strata from the Aertashi section in the southwestern Tarim Basin (Fig. 1) when the epicontinental sea was still covering part of Central Asia (Bosboom et al., in press). Previous studies using sclerochronology from Eocene bivalve shells focused on stable oxygen isotope ratios $\delta^{18}O_c$ as seawater temperature recorder (Ivany et al., 2000; Buick and Ivany, 2004; Ivany et al., 2004). These studies, however, used bivalves from open oceans conditions, where seawater $\delta^{18}O_{sw}$ can be assumed to



Study area. a. Modern geographical map of Eurasian continent. b. General topographic and tectonic map of the Tarim Basin and surrounding area. F. stands for fault; S. stands for suture; L. stands for line. The topography is a courtesy of S. Dominguez. c. Paleogeographical Palaeogeographical map for the Middle Eocene (Lutetian) showing sea-–land distribution (modified after Bosboom et al., 2011). AT: localisation of the studied Aertashi section (37°58′N, 76°33′E).

Fig. 1.