Earth and Planetary Science Letters 485 (2018) 99–110

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

# Asian monsoons and aridification response to Paleogene sea retreat and Neogene westerly shielding indicated by seasonality in Paratethys oysters

Laurie Bougeois [a,*], Guillaume Dupont-Nivet [b,c,d], Marc de Rafélis [e], Julia C. Tindall [f], Jean-Noël Proust [b], Gert-Jan Reichart [g], Lennart J. de Nooijer [g], Zhaojie Guo [d], Cholponbelk Ormukov [h]

[a] *Ministère de l'Éducation nationale, Académie de Montpellier, France*
[b] *Géosciences Rennes, UMR-CNRS 6118, Université de Rennes 1, Rennes, France*
[c] *Department of Earth and Environmental Sciences, Potsdam University, Germany*
[d] *Key Laboratory of Orogenic Belts and Crustal Evolution, Ministry of Education, Beijing, China*
[e] *GET, Observatoire Midi Pyrénées, CNRS, IRD, Université de Toulouse, Toulouse, France*
[f] *School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK*
[g] *Department of Marine Geology, Royal Netherlands Institute for Sea Research, Texel, The Netherlands*
[h] *Central Asian Institute for Applied Geosciences (CAIAG), T. Frunze rd. 73/2, 720027, Bishkek, Kyrgyzstan*

ARTICLE INFO

*Article history:*
Received 10 June 2017
Received in revised form 10 December 2017
Accepted 16 December 2017
Editor: A. Yin

*Keywords:*
Eocene monsoon
aridification
Paratethys sea
Central Asia
seasonality
bivalves

ABSTRACT

Asian climate patterns, characterised by highly seasonal monsoons and continentality, are thought to originate in the Eocene epoch (56 to 34 million years ago – Ma) in response to global climate, Tibetan Plateau uplift and the disappearance of the giant Proto-Paratethys sea formerly extending over Eurasia. The influence of this sea on Asian climate has hitherto not been constrained by proxy records despite being recognised as a major driver by climate models. We report here strongly seasonal records preserved in annual lamina of Eocene oysters from the Proto-Paratethys with sedimentological and numerical data showing that monsoons were not dampened by the sea and that aridification was modulated by westerly moisture sourced from the sea. Hot and arid summers despite the presence of the sea suggest a strong anticyclonic zone at Central Asian latitudes and an orographic effect from the emerging Tibetan Plateau. Westerly moisture precipitating during cold and wetter winters appear to have decreased in two steps. First in response to the late Eocene (34–37 Ma) sea retreat; second by the orogeny of the Tian Shan and Pamir ranges shielding the westerlies after 25 Ma. Paleogene sea retreat and Neogene westerly shielding thus provide two successive mechanisms forcing coeval Asian desertification and biotic crises.


## 1. Introduction

Asian climate, governing the livelihood of billions of people, is characterised by high seasonality. In southeastern Asia seasons are expressed by high summer rainfall compared to winter in response to the archetypal monsoonal circulation. In contrast, central continental Asia records extreme seasonal temperature and minimal precipitation (Araguás-Araguás et al., 1998). The origin and past evolution of these seasonal patterns remain poorly constrained although they are key to deciphering their forcing mechanisms and to validate climate model predictions. To understand Asian climate, it is crucial to assess and quantify its past seasonality, in particular during the Eocene epoch (56 to 34 Myr ago), when high atmospheric $pCO_2$ levels kept global climate in a greenhouse state and the India–Asia collision shaped the paleogeographic features that would define Asian climate patterns (Zachos et al., 2001; Pagani et al., 2005).

During this epoch, the India–Asia collision resulted in the growth of the Tibetan Plateau and Himalayas. These orogenies are traditionally held responsible for the establishment of monsoons and desertification (Guo et al., 2002; France-Lanord et al., 1993) by creating orographic barriers as well as increasing atmospheric circulation through enhanced heat transfer from the plateau surface to the atmosphere (Molnar et al., 2010; Boos and Kuang, 2010; Wu et al., 2012; Liu et al., 2012). These environmental changes during Cenozoic have been called upon to explain major biotic events

* Corresponding author.
*E-mail address:* laurie.bougeois@gmail.com (L. Bougeois).

https://doi.org/10.1016/j.epsl.2017.12.036

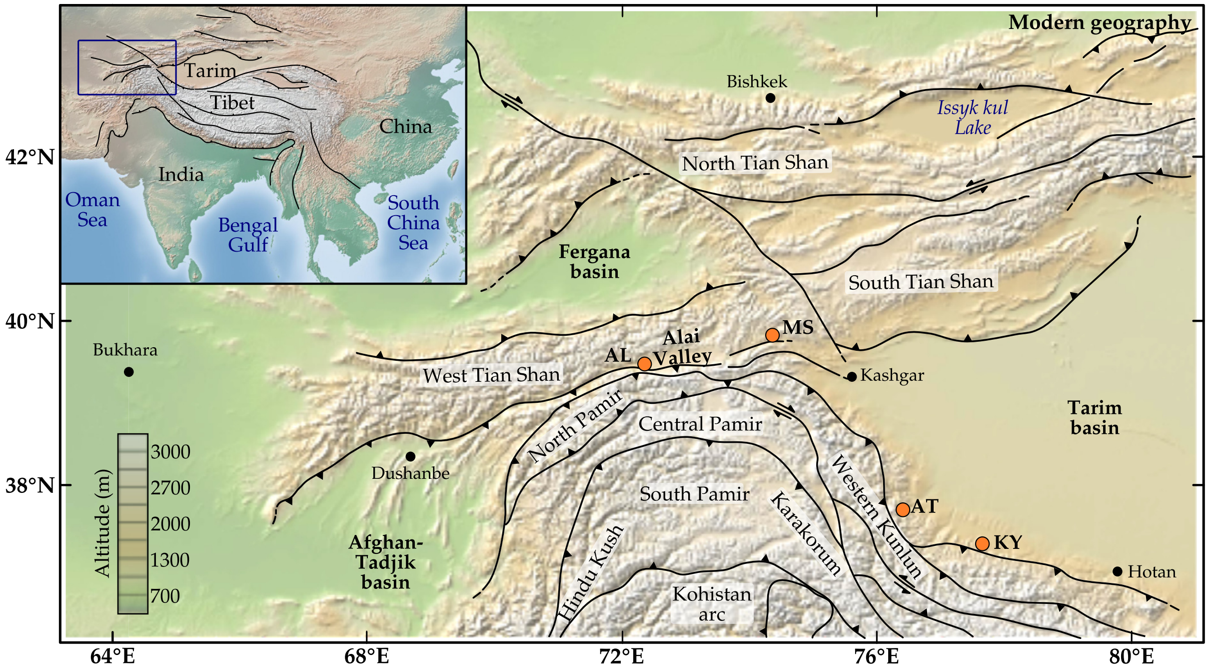


**Fig. 1.** Localisation of study area. Modern topographic map of the study area showing the main tectonic features and the localisation of the sampled sedimentary sections (AL: Alai Valley, 39.6°N, 72.4°E; MS: Mine, 39°51′N, 74°32′E; AT: Aertashi, 37°58′N, 76°33′E; KY: Keyliand, 37°27′N, 77°86′E). The position of the sites experienced no statistically significant latitudinal tectonic motion since the time of deposition (Bougeois et al., 2014).

(Favre et al., 2015) such as the Mongolian Remodelling (Kraatz and Geisler, 2010; Fortelius et al., 2014) and the emergence of grassland and C4 plants (Edwards et al., 2010). Another competing forcing mechanism during this epoch is the strong global climate cooling from a greenhouse to an icehouse state. Models suggest that strong monsoonal circulation was maintained by warmer Eocene conditions (Licht et al., 2014) but subsequent global cooling led to Asian aridification and decreasing monsoonal intensity mostly due to diminished moisture transport (Dupont-Nivet et al., 2007; Licht et al., 2014). We focus here on the influence of the large epicontinental Proto-Paratethys sea that formerly covered Eurasia (Bosboom et al., 2017). It is also recognised as a major driver by modelling studies suggesting that its presence would dampen the seasonal thermal contrast between the continent and surrounding oceans negating the possibility of intense Eocene monsoons (Ramstein et al., 1997; Zhang et al., 2007). Also the sea potentially provided an important moisture source transported by the westerlies into Asia (Dupont-Nivet et al., 2007; Zhang et al., 2012). The sea fluctuations and retreat may therefore have modulated Asian environments leading to desertification and increasing monsoonal circulation (Ramstein et al., 1997).

In principle, climate proxies of seasonality contrasts from the sedimentary records should enable to disentangle the respective contributions of forcing mechanisms suggested by climate models. If the sea indeed dampened the ocean–continent thermal contrast, a temperate climate with low seasonality would be expected. In addition, seasonality can be used to discriminate between monsoonal vs. westerly moisture sources because they have opposite precipitation patterns: monsoons are dominated by summer precipitation while westerlies are characterised by winter precipitation. Existing records of aeolian loess-like deposits (Licht et al., 2014), pedogenic stable isotope (Caves et al., 2015) and fossil pollen studies (Dupont-Nivet et al., 2008) point to monsoonal circulations with Asian interior aridity despite the Proto-Paratethys sea presence. However, no quantitative records of Eocene seasonality from this area have been hitherto produced due to the paucity of appropriate records and reliable methods to extract them.

To constrain seasonality, Bougeois et al. (2014, 2016) developed a geochemical high resolution multi-proxy approach (oxygen stable isotopes – $\delta^{18}O$ – and Mg/Ca elemental ratios) on pilot samples from fossil oyster shells of the Proto-Paratethys itself. Here we apply this approach to numerous specimens and complement this geochemical data with sedimentological paleoenvironmental analyses and a coupled atmosphere–ocean general circulation model – GCM – constraining independently oceanic and atmospheric temperatures, precipitation patterns and isotopic composition in the Proto-Paratethys region. Furthermore, the isotopic signatures of Paleogene to Neogene pedogenic carbonates are compared to the marine data to identify the evolution of moisture sources during sea retreat, regional uplift and global cooling.

## 2. Geological setting

This study focuses on the well-dated Proto-Paratethys sea sediments exposed today in the Tarim and Alai Valley basins over the foothills of the Central Asian (Pamir and Tian Shan) ranges (Bosboom et al., 2017, 2014a,b) (Fig. 1) that uplifted since the early Miocene (ca. 25 Ma; Sobel et al., 2006; Zheng et al., 2015; Blayney et al., 2016). In the early Eocene (ca. 55 Ma) the sea reached its maximum expansion, from the Tarim basin to the Mediterranean and linked Arctic and paleo-Indian oceans (Dercourt et al., 1993). After this, the sea retreated westward. It was barely reaching the Tarim basin towards the Late Eocene (ca. 37 Ma) and had shrunk to the Caspian sea's present position by the 34 Ma Eocene–Oligocene transition (Bosboom et al., 2014b). The retreat therefore likely results from tectonic deformations in response to the early Eocene India–Asia collision onset (Molnar et al., 2010). However, the eustatic drop associated with global late Eocene cooling that lead to the Antarctic ice sheet at the Eocene–Oligocene transition, probably also contributed to the sea retreat (Bosboom et al., 2014b).