Earth and Planetary Science Letters 479 (2017) 144–155

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

Intensified episodes of East Asian Winter Monsoon during the middle through late Holocene driven by North Atlantic cooling events: High-resolution lignin records from the South Yellow Sea, China

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A R T I C L E I N F O

Article history:
Received 5 March 2017
Received in revised form 10 September 2017
Accepted 11 September 2017
Available online 2 October 2017
Editor: M. Frank

Keywords:
lignin
East Asian Monsoon
Bond cycles
ENSO
hydrodynamic sorting effect
Holocene

A B S T R A C T

The varying intensity of the East Asian Winter Monsoon (EAWM) governs the strength of the counter-clockwise surface circulation of the South Yellow Sea and the redistribution of sediment and terrestrial organic material that had accumulated on the shallow shelf during the summer season into the central part of that basin. We compiled a time series spanning about 6.3 ka of terrestrial lignin proxies from sediment core N02 from Central Yellow Sea Mud that has well-preserved high-resolution sedimentary records (24 yr/cm average spacing). The "hydrodynamic sorting effect" driven by century-scale climate variation in the strength of the EAWM exerts the main underlying control on the variation of lignin proxies in marginal sea sediments, rather than paleovegetation variability in provenance region driven by the East Asian Summer Monsoon (EASM). Our lignin proxies data imply that North Atlantic climate forcing recorded by ice-rafted debris ("Bond cycles") played a critical role in generating EAWM variability on these centennial timescales during the Holocene. These variations of lignin records are superimposed on general multi-thousand-year trends that appear to mirror the relative frequency and intensity of the El Niño Southern Oscillation (ENSO). Our results indicate that lignin can be adopted as an additional reliable proxy for paleoclimate evolution, at least in South Yellow Sea area.

1. Introduction

The past responses of the modern global climate system to excursions provide a set of ground-truths for climate models of future excursions. During the middle through late Holocene, the northern hemisphere underwent several century-long warming and cooling excursions that profoundly affected regional civilizations (Mayewski et al., 2004; Wanner et al., 2008). In order to compile quantitative records of the terrestrial and marine responses to these episodes, a global set of high-resolution records is required. For much of East Asia, the most important climatic changes are in the relative amounts of rainfall during the summer monsoon season and in the strength of dry cold winds of the winter monsoon (Jia et al., 2015; Liu et al., 2015).

Studies of the Holocene variability of the East Asian Winter Monsoon (EAWM) based on interpretations using different depositional systems including eolian, lake and marine sediments, have shown that changes in the East Asian paleoclimate are a regional expression of near-global major abrupt, decadal to millennial-scale climate changes (see details in Appendix Section A). In particular, some of these studies concluded that century-scale episodes of increased EAWM or enhanced coolings coincided with episodes of apparent coolings of the North Atlantic region (e.g., Fan et al., 2016; Wang et al., 2005; Sagawa et al., 2014; Sun et al., 2012). A record of North Atlantic cooling events compiled by Bond et al. (2001) from drift-ice tracers in cores indicate episodic extensions of cold polar surface water southward and eastward.

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http://dx.doi.org/10.1016/j.epsl.2017.09.031
0012-821X/

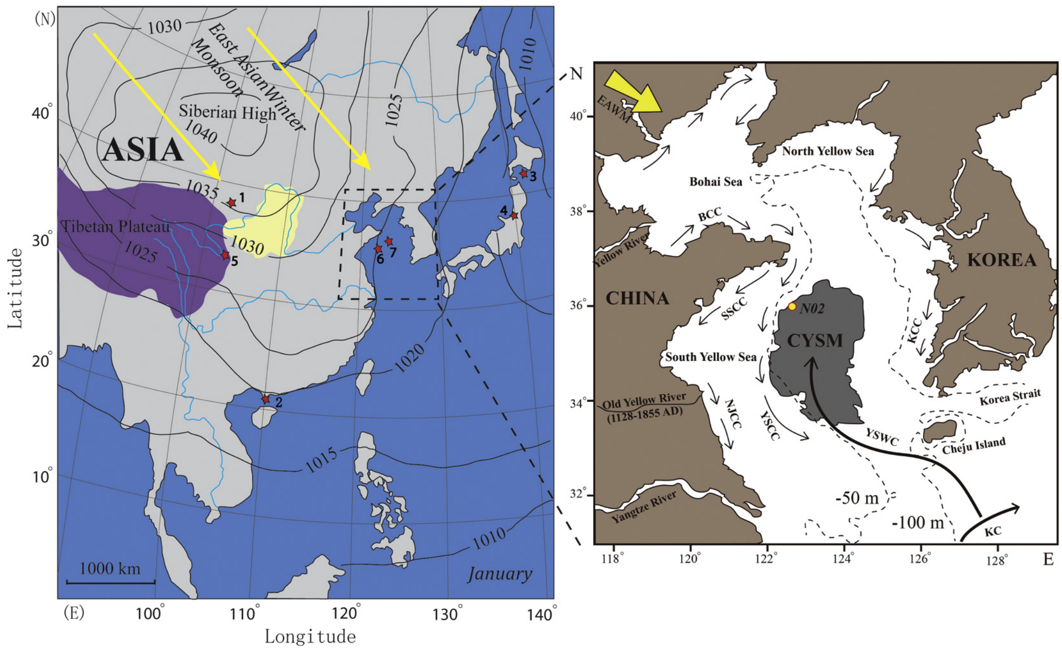

Fig. 1. Locations of studies for proxies of the EAWM and the typical winter current circulation pattern of the South Yellow Sea. In the schematic large-scale diagram, the purple area is Tibetan Plateau, the yellow area is Chinese Loess Plateau, and numbered dots refer to the corresponding studies in Appendix Table 1. In the diagram of the South Yellow Sea during winter conditions, the shaded area with our sediment core N02 is the Central Yellow Sea Mud basin, yellow EAWM arrow is the typical direction of the East Asian Winter Monsoon winds, and the current abbreviations are BCC (Bohai Coastal Current), SSCC (South Shandong Coastal Current), NJCC (North Jiangsu Coastal Current), YSCC (Yellow Sea Coastal Current), KCC (Korea Coastal Current), YSWC (Yellow Sea Warm Current), and KC (Kuroshio Current). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The main extreme cooling intervals, later called "Bond cycles", peak at ca. 500, 1400, 2800, 4400, 5500, 8100, 9400, 10300, and 11100 yr BP. Although their driving cause remains uncertain, some of these "Bond cycles" do appear to display hemisphere-scale climatic teleconnections (e.g., Fan et al., 2016; Wang et al., 2005; Wanner et al., 2008; Sagawa et al., 2014). Therefore, to demonstrate that these "Bond cycles" are indeed synchronous global coolings requires a widespread array of reliable and verified high-resolution paleoclimate records from different settings and regions.

Climate forcings play an indirect but very important role in the temporal evolution of organic matter accumulation in sediment cores of South Yellow Sea. The efficiency and magnitude of the processes of hydrodynamic resuspension and redeposition of the summer accumulations into the Central Yellow Sea Mud should be enhanced during climatic intervals characterized by stronger EAWM winds (see Appendix Section B). Therefore, the dating and analysis of types of terrestrial components of cores from these redeposited muds of central South Yellow Sea basin can be used to determine the history of the winter monsoon phase.

Lignin, the most important terrestrial macrobiomarker, because it constitutes 20∼30% of vascular plant tissues, is essentially absent from the tissues of marine organisms and is relatively resistant to degradation compared to other plant organic material (e.g., Li et al., 2014; Tesi et al., 2007; Wang et al., 2015). Lignin-derived phenols are indicative of certain plant tissue types and of the degradation processes of terrestrial organic matter (Tesi et al., 2007). Therefore, lignin and its phenols are valuable tracers for the processes of input, transport and deposition of terrestrial organics from river watersheds onto the inner shelf and then into deeper marine depocenters (e.g., Kuzyk et al., 2008; Tesi et al., 2007).

In our study, we obtained high-resolution lignin records of a reference sediment core from Central Yellow Sea Mud to elucidate the paleoclimatic evolution of the EAWM during the past 6300 yr. The main objective is to investigate the underlying mechanisms and timing of variability in signatures of lignin records in the Central Yellow Sea sediments, with a focus on the effects of physical processes driven by climate forcings. When these lignin proxies were merged with other indications of regional climate, it does indeed appear that most of the century-scale episodes of enhanced winter monsoon conditions in the South Yellow Sea region coincide with "Bond cycles" of North Atlantic cooling.

2. Methods and phenol proxies

2.1. Coring, chronology, and lithology

The gravity core N02 was recovered from the Central Yellow Sea Mud (36°3.6′ N, 122°39.0′ E, 64 m water depth) by R/V Dong-Fang-Hong 2 affiliated with the Ocean University of China during the spring of 2011 (Fig. 1). The continuous sediments within the 260-cm core span about 6.3 ka. The split core was described and then subsampled for lignin analyses at 1-cm intervals, therefore yielding an average resolution of about 24-yr.

The age model for core N02 was obtained by accelerator mass spectrometry (AMS) ^{14}C dating of mixed benthic foraminifera at Beta Analyses Company (USA) and Dating Laboratory at Peking University (Beijing, China), and the results are shown in Table 1. Dating errors are less than ±164 yr within the 1σ interval of the AMS ^{14}C method. All dates were calibrated to calendar years before "present" (before 1950 AD, or BP) using the CALIB 6.1.1 program with a correction factor Delta $R = -128 \pm 35$ yr. Delta R was the average of three data points, one from Qingdao and two from the Korean peninsula (Southon et al., 2002; Kong and Lee, 2005). The top of core N02 was too young to reach the minimum value of the correction range and cannot be corrected, therefore we set its age as 0 cal yr BP. The chronology was established by linear interpolation between the calibrated ages. Sediment accumulation rates between the dated horizons range from 32 to 82 cm/ka with a mean accumulation rate of 42 cm/ka (Fig. 2).

Grain size analyses were performed on the 129 subsamples using a Mastersizer-2000 laser particle-size analyzer from 0.02 to