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Natural and anthropogenic impacts on environmental changes over the past 7500 years based on the multi-proxy study of shelf sediments in the northern South China Sea

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ABSTRACT

The evolution of the Asian summer monsoon (ASM) over the past 7500 years and regional human–environment interaction over the past 2000 years were investigated using high-resolution multi-proxy records from a well-dated sediment core (YJ Core) from the northern inner shelf of the South China Sea. The chemical index of alteration (CIA) of bulk samples were determined to infer changes in regional chemical weathering intensity, and $\delta^{13}C_{org}$ and Total Organic Carbon (TOC) measurements were used to indicate changes in the strength of fluvial discharge. The results suggest intense chemical weathering and strong fluvial discharge during the interval 6800–3500 cal yr BP, followed by a weakening in both factors from 3500 to 2000 cal yr BP, and intensification again after 2000 cal yr BP. Comparison with climatic records from different monsoonal regions indicates that the ASM controlled both the chemical weathering and fluvial discharge intensity before 2000 cal yr BP. The enhanced chemical weathering and fluvial discharge during the past 2000 years coincide with an increase in both magnetic susceptibility (χ_{lf}) and frequency-dependent magnetic susceptibility (χ_{fd}), as well as an increase in sedimentary Cu and Pb concentrations. This interval also saw an increase in the population of Guangdong Province. Therefore, it is inferred that an increase in soil erosion and the use of metal tools were stimulated by a growing human population and the expansion of agricultural and mining practices. The present results suggest that enhanced human activity during the past 2000 years has overall overwhelmed the natural climatic controls on the environment and landscape of the Ling-Nan region (southernmost China).

1. Introduction

Acquiring a better knowledge of the interactions between past climate, human activity, and environmental change is important if we are to understand present and future interactions among these systems (Dearing et al., 2006, 2008). In recent years, there has been an increasing awareness that human activities have the capacity to alter global climate and landscapes, resulting in a great number of contemporary issues such as the increasing frequency and magnitude of extreme climatic events, heavy metal pollution, soil erosion and degradation, and lake eutrophication. It seems to stimulate the creation of a new, human-driven geological epoch, namely the Anthropocene (Crutzen, 2002). Paleoenvironmental data can provide a historical perspective on such issues by providing case studies of human effects on ancient environments. The reconstruction of past climate–human–environment interactions not only serves as a "baseline" for comparison with the present, but can be used to improve our understanding of environmental thresholds and the complex non-linear behavior of these systems (Dearing et al., 2006; Froyd and Willis, 2008). These historical perspectives provide new insights into the future resilience and sustainability of our ecosystems and landscapes (Dearing et al., 2008).

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Numerous studies of the interaction between human societies, environment, and climate change have been carried out in different locations around the world (e.g., Corella et al., 2013; Gelorini and Verschuren, 2013; Malkiewicz et al., 2016; Marinova et al., 2012; McGregor et al., 2009; Morales et al., 2009). Similarly, in the Asian monsoon region, recent studies have explored the relationships between human societies, their environment, and past climates (e.g., Dearing et al., 2008; Hu et al., 2013; Li et al., 2014a; Wan et al., 2015; Wu et al., 2015). They reached a general understanding that along with the growing of the human population and technological advancements during the late Holocene, human influences on the natural environment have increased dramatically and have thus masked some of climatic signals in sedimentary archives. Therefore, an understanding of climate and human activities on longer time scales, as well as their impacts on terrestrial ecosystems, is essential if we are to disentangle both signals and generate records of each accurately. However, the beginning of the human induced shaping of landscapes and the regional differences in timing and extension of those changes are widely debated. Well dated and high resolution data from wide regions are needed to shed light on human–environment interactions.

Variability in the Asian summer monsoon (ASM), which is an integral part of the global climate system, has a significant effect on natural ecosystems, agricultural production, economic activity, and societal stability within its area of influence (IPCC, 2013; Yasuda and Shinde, 2004; Zhang et al., 2011). Therefore, details of past variations in the ASM are critical for exploring its underlying forcing mechanisms and for predicting regional climate change. In southern China, existing reconstructions of Holocene ASM intensity have largely relied on paleoprecipitation proxy records from peat deposits (Zhong et al., 2015, 2017; Zhou et al., 2005), lacustrine sediments (Jia et al., 2015; Wang et al., 2016; Wu et al., 2012), speleothem deposits (Dykoski et al., 2005; Wang et al., 2005), Pearl River Delta sediments (Hu et al., 2013; Strong et al., 2013; Yu et al., 2012; Zong et al., 2006), fossil coral (Deng et al., 2014; Yu et al., 2005), and marine sediments (Dai and Weng, 2015; Hu et al., 2012; Huang et al., 2016). The results of these studies show a general decline in ASM intensity from 7500 cal yr BP to the present. However, many of these records have relatively low resolution and poorly constrained age models. This limitation hinders comparisons with high-resolution records in other monsoonal regions. Thus, high-resolution records from southern China with robust chronologies are essential in gaining a better understanding of monsoonal variability during the Holocene.

The northern South China Sea (SCS), which adjoins the source of the ASM, is sensitive to climatic fluctuations driven by the ASM (Huang et al., 2011; Hu et al., 2012). In addition, the adjacent Ling-Nan area of China has a long history of human occupation, agriculture, and mining (Li et al., 1991; Liu et al., 2010; Zong et al., 2010). Thus, this is an excellent region for reconstructing regional climate oscillations and investigating the impact of human activities on the natural environment. Here, a high-resolution multi-proxy marine sediment record is presented with a robust chronology derived from the northern inner shelf of the SCS, spanning the past 7500 years. To reconstruct various elements of monsoon evolution, land-use, and mineral resource extraction during the Holocene, records of chemical weathering proxies (CIAm) were generated along with the concentration and isotopic composition of organic carbon (TOC and $\delta^{13}C_{org}$), magnetic parameters (χ_{lf} and χ_{fd}), and elemental concentrations (Cu and Pb) throughout the sediment core. The interactions between Holocene climate variability, human activity, and environmental change were investigated. The results provide new insights into the timing and intensity of human activity in southern China during the past 2000 years.

2. Regional setting, materials, and methods

2.1. Regional setting

The Pearl River is the third longest river in China and discharges into the northern SCS where a mud belt covers the inner shelf and stretches along the coast to the west of the Pearl River mouth (Fig. S1; Qin, 1963; Owen, 2005). Recent works have revealed that the mud deposits on the northern inner shelf of the SCS originate mainly from sediment discharge from the Pearl River and are transported to the southwest by coastal currents (Fig. S1; Liu et al., 2012, 2014b, 2016; Wang, 2007). Based on an examination of clay minerals in surface sediments, Liu et al. (2012) estimated that the Pearl River supplied 79% of the sediment in the study region. In addition, the mean annual river runoff from the Pearl and Moyang rivers are estimated to be $3283.0 \times 10^8\,m^3$ and $59.1 \times 10^8\,m^3$, respectively (Wang, 2007). Based on these data, the Moyang River is small compared with the Pearl River and makes a small contribution despite its proximity to the YJ Core (Wang, 2007). The Pearl River discharges suspended sediment of 8735×10^4 t/yr into the SCS (Wang, 2007). The area for this study covers a region of subtropical to tropical maritime monsoon climate. The annual mean temperature is around 14 °C–22 °C. The annual mean precipitation ranges from 1200 mm to 2200 mm, with over 80% of rainfall occurring between April and September (Zong et al., 2009). In the summer wet seasons (April–September) when the summer monsoon prevails, about 98.7% of the sediment load, and 77.8% of the water are delivered (Jilan, 2004). Suspended sediments consist primarily of silt and clay (Huang et al., 1982; Zhao, 1990).

The inner continental shelf (water depth < 60 m) has a bed slope of around 0.08° (Feng and Zheng, 1982). The tides of the region are irregularly semidiurnal in character (Wang, 2007). On the inner shelf, the Guangdong Coastal Current flows westward through the year and has an average speed of 0.2–0.3 m/s (Wang, 2007). Due to the coastal current, the fine-grained sediment from the Pearl River mainly travels to the southwest SCS (Fig. S1).

2.2. Materials

An 8.39-m-long sediment core, the YJ Core (112°8.08′E, 21°31.44′N), was recovered by using a gravity core at 21 m water depth in the northern inner shelf of the SCS in the summer of 2013 (Fig. 1). The core is composed mainly of grey clay, yellow-brown clay, grey clayey silt, and yellow-brown clayey silt. This study focuses on the uppermost 6.1 m, which consists mainly of homogeneous grey fine-grained muddy sediments containing occasional shells. The sediment core was cut longitudinally and then sectioned at 1–6 cm intervals in the laboratory. The samples were stored at 4 °C prior to analysis.

2.3. Age model

Chronological controls for the YJ Core were established using a combination of ^{210}Pb and ^{137}Cs dates in the upper 13 cm (Fig. 2a), and AMS ^{14}C dates from 18 shell samples (Table 1; Fig. 2b). The chronology of the uppermost sediments were determined by the ^{210}Pb–^{137}Cs dating method, using the constant rate of supply (CRS) model (Appleby and Oldfield, 1978; Pheiffer Madsen and Sørensen, 1979). The ^{137}Cs was used to confirm the ^{210}Pb chronology. The initial peak of ^{137}Cs activity at 9 cm can probably be ascribed to the culmination of nuclear weapons testing in 1963 AD. A peak in ^{137}Cs activity at 7 cm corresponds to the China's largest atmospheric nuclear test in 1976 AD (Norris et al., 1994). A single maximum ^{137}Cs at 5 cm may be attributed to the Chernobyl accident in 1986 AD.