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Magnetostratigraphy and paleoenvironmental events recorded in a late Cenozoic sedimentary succession in Huaibei Plain, East China

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A B S T R A C T

The thick late Cenozoic deposits of Huaibei Plain provide a record of paleoenvironmental changes in the northern and southern transitional zone of eastern China, and of the evolution of the Asian monsoon system. A detailed magnetostratigraphic study of the Huainan (HN, 481.45-m deep) drill core from the center of Huaibei Plain reveals a magnetic polarity sequence from chron C4n.2n to chron C1n, spanning the interval from ~8 Ma to the present; it is the first reliable magnetostratigraphic chronology for the late Miocene to present for Huaibei Plain. The stratigraphic sequence contains three intervals characterized by major peaks in magnetic susceptibility (at depths of 58.8 m, 108.0 m and 312.4 m), which can be used as isochronous marker beds for regional stratigraphic correlations in Huaibei Plain. Major changes in sediment grain-size occur at 7.0 and 1.7 Ma, corresponding to pronounced environmental shifts, which we consider reflect the respective strengthening of the South Asian summer monsoon and East Asian winter monsoon at these times.

1. Introduction

Reconstructing the Cenozoic environmental history of Huaibei Plain in eastern China is important for improving our understanding of the environmental evolution of the region, as well as of the East Asian monsoon (Jin, 1990; Shu, 2012; Guan et al., 2016; Zhang et al., 2016; Zhou et al., 2016). Most records of late Cenozoic changes in the East Asian monsoon are from terrestrial sediment sequences in central-western China (An et al., 2001; Ding et al., 2001; Guo et al., 2002; Sun et al., 2006; Deng et al., 2018) and from marine sediments in the South China Sea (Wang et al., 2003, 2016; Tian et al., 2011). In contrast, in eastern China, there are few terrestrial records with detailed chronologies, although such records may contribute substantially to our understanding of the evolution of the East Asian monsoon during the late Cenozoic.

Huaibei Plain contains sedimentary sequences that record changes in the East Asian monsoon during the late Cenozoic (Jin et al., 1987; Zhang, 2009; Qin et al., 2015; Zhou et al., 2016). To date, however, few studies of sedimentary sequences in Huaibei Plain have yielded long-term chronologies, since most of the investigations were made before 1990 when drilling did not reach bedrock, and therefore the recovered cores did not span the entire sedimentary succession. Preliminary paleomagnetic studies of Cenozoic sediments from Huaibei Plain were conducted more than two decades ago by Quan Jin and colleagues (Jin et al., 1986, 1987; Jin, 1990; Zhang, 2016) and by Zhenjiang Yu and colleagues (Yu, 1988; Yu and Huang, 1993; Yu and Peng, 2008). Jin (1990)

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estimated that the base of the Huaibei Plain sedimentary sequence is older than 3.4 Ma, whereas Yu and Huang (1996) proposed an age greater than 4.5 Ma. However, these estimates were based on cores that did not reach bedrock and therefore they did not sample the base of the sedimentary sequence.

In 2012 a drilling project was conducted at Huainan in the center of Huaibei Plain with the aims of providing the first detailed long-term chronological framework for the region, and producing a detailed paleoenvironmental record and exploring its relationship with the evolution of the East Asian monsoon. During the project, a continuous 481.45-m-long drill core was obtained, consisting mainly of fluvio-lacustrine sediments, which were anticipated to provide information about late Cenozoic paleoenvironmental and paleoclimatic changes in eastern China and to document the evolution of the East Asian monsoon.

Here, we present the results of a detailed magnetostratigraphic and paleoenvironmental study of the entire fluvio-lacustrine succession. The magnetostratigraphy, together with age constraints provided by tephra layers and mammalian fossils, is used to generate a robust chronological framework which enables us to interpret the observed changes in sediment grain-size and magnetic susceptibility. Finally, we discuss the results in the context of late Cenozoic environmental events in the region and their linkage with the evolution of the East Asian monsoon. Our results provide the first long-term chronological framework for sediments in Huaibei Plain, and they potentially improve our understanding of late Cenozoic environmental change in eastern Asia.

2. Regional environmental background, sedimentary lithology and sampling

2.1. Geological setting

Huaibei Plain, in central East China, is an alluvial–proluvial plain that developed at the base of a faulted basin during the Mesozoic, between the Yellow River and the Huaihe River. It covers an area of 37,421 km^2 (Hu et al., 2017) (Fig. 1a and b) and extends from 32°25′–34°35′N, 114°55′–118°10′E (Jin, 1990; Hu et al., 2014). It is bounded by the Yellow Sea to the east, the Funiu Mountains to the west, the Yellow River to the north, and the Dabie Mountains to the south (Cao, 2009). The surface of the plain is slightly inclined from northwest to southeast with a slope gradient of 1:8000, and the elevation above sea level varies from 15 to 50 m (Fig. 1b) (Jin, 1990; Wu et al., 2009). The 340-km-long Huaihe River flows from west to east through the southern part of Huaibei Plain, dividing it into northern and southern parts (Fig. 1b). The region lies within the warm and semi-humid climatic zone and has four distinct seasons (Jin, 1990).

Successions of unconsolidated Cenozoic sediments with thicknesses of several 100s of meters to more than 1000 m have accumulated in Huaibei Plain, with much thicker sequences in the west than in the east (Xie et al., 2013). These sediments consist primarily of alternating layers of sands, silty sands, and clays (Wu and Wu, 2014; Hu et al., 2017). The area has experienced tectonic subsidence during the Quaternary (Zhou et al., 2016) and most of the surface of the plain is covered by Quaternary strata, except for small areas of exposed bedrock in the northeast and west (Qian et al., 2015). Due to the flooding and diversion of the Yellow River, Holocene deposits in the northern part of the plain occur mainly along the tributaries of the Huaihe River, with typical thicknesses of several meters to ~10 m (Wu and Wu, 2014; Qian et al., 2015).

2.2. Lithology of the Huainan (HN) core

During April and May of 2012, a core (HN) was recovered using rotary drilling by the National Engineering Laboratory for Ecological Environmental Protection in Coal Mines. The core site is near the town of Guqiao in the middle of Huaibei Plain, about 30 km north of the Huaihe River (32°50.123′N, 116°30.167′E) (Fig. 1b). Drilling reached a depth of 481.45 m, with an average core recovery of 94%, and penetrated the entire sequence of Cenozoic sediments, reaching the underlying Permian sandstone bedrock. The core site is in the Huaibei subsidence zone, which has experienced continuous sediment accumulation during the late Cenozoic (Guo et al., 1992). There are no significant sedimentary discontinuities in the HN borehole and the sedimentary sequence is essentially complete, without significant hiatuses.

The lithology of the HN core was divided into eight lithological units (Units 1–8) from top to bottom, according to variations in grain size, bedding, color, and structure (Fig. 2). They are described as follows.

Unit 1 (0–52.4 m) is dominated by yellow clays, silty clays, and silts, and contains a few layers of calcium carbonate nodules. Layers of brown silty clays (21.2–29.0 m) and yellow silts (42.5–48.4 m) exhibit conspicuous horizontal bedding. The unit is interpreted as alluvial plain facies.

Unit 2 (52.4–69.6 m) is dominated by black to dull grayish-black clayey silts and silts with conspicuous horizontal bedding; it is interpreted as lacustrine facies.

Unit 3 (69.6–108.0 m) is dominated by yellow–yellowish silty clays and clays, containing numerous calcium carbonate nodules and a few layers of Fe–Mn concretions. Layers of yellow silty clays (79.6–86.4 m) and light grayish-black silty clays (98.4–103.6 m) exhibit conspicuous horizontal bedding. These characteristics indicate alluvial plain facies, like Unit 1.

Unit 4 (108.0–142.0 m) consists of yellowish-green or grayish-green silts, fine sands, and coarse sands with numerous calcium carbonate nodules and Fe–Mn concretions. A light greenish-gray coarse sand layer, containing gravels with clasts of 0.5–2.0 cm diameter, is present from 132 to 136 m. The unit is interpreted as fluvial facies.

Unit 5 (142.0–207.2 m) consists of greenish-gray coarse sands, light greenish-gray and gray fine sands; clayey silts with conspicuous horizontal bedding occur from 166.4 to 175.6 m and from 184.0 to 188.0 m. The unit is interpreted as predominantly fluvial facies.

Unit 6 (207.2–398.4 m) is composed of dull greenish-gray coarse sand interbedded with greenish-gray sandy clays. The unit is interpreted as representing the alternation of fluvial and lacustrine facies.

Unit 7 (398.4–460.8 m) is dominated by greenish-gray clays with two layers of reddish silty clays (from 415.0 to 418.0 m and 431.2–432.4 m). The unit is interpreted as lacustrine facies.

Unit 8 (460.8–481.45 m) consists of dull red-reddish silt and clayey silts, containing numerous calcium carbonate nodules and Fe–Mn concretions. The unit is interpreted as representing a predominantly terrestrial, oxidizing environment.

2.3. Sampling

A total of 451 samples for paleomagnetic analysis were obtained at a ~1 m interval throughout the core and placed in nonmagnetic square plastic boxes of 8 cm^3 volume. The horizontal orientation of the samples is arbitrary because the core was obtained using mud-flush rotary drilling techniques and it did not have a consistent horizontal orientation. The samples were mainly taken from fine-grained intervals (clay, silt and fine-grained sand); however, several samples of coarser sediments were also obtained.