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Paleoenvironmental background of the Early Pleistocene *Gigantopithecus* fauna in Bubing Basin, south China

Shengmin Huang [a, b], Hanlie Hong [a, **], Christopher J. Bae [c, *], Liuling Cheng [a], Dawei Li [a], Wei Liao [a], Ke Yin [a], Chaowen Wang [d], Wei Wang [e]

[a] School of Earth Science, China University of Geosciences, Wuhan 430074, China
[b] Nanning Museum, Nanning 530012, China
[c] Department of Anthropology, University of Hawaii at Manoa, 2424 Maile Way, 346, Saunders Hall, Honolulu, HI 96822, USA
[d] Gemmological Institute, China University of Geosciences, Wuhan 430074, China
[e] Guangxi Museum of Nationalities, Nanning 530022, China

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ABSTRACT

Thanks to the presence of the enigmatic *Gigantopithecus* fossils, vertebrate paleontologists have spent much time analyzing the Pleistocene faunas of southern China. Although research has been conducted in the region for more than one half century, the vast majority of this research has focused on the direct analysis of the associated vertebrate fossils, particularly for taxonomic identification purposes. In order to develop a firmer understanding of the paleoenvironment in which these various taxa lived there is still a relative paucity of data derived from other lines of evidence besides taxonomic identifications. Here, we contribute to these paleoenvironmental reconstructions of southern China by presenting the results of clay mineral composition and geochemical analyses of the deposits from the Early Pleistocene Mohui Cave (Bubing Basin, Guangxi). In general, the Mohui Cave clay mineral samples are dominated by kaolinite, which indicates a warm and humid climate. The relatively high content of smectite in Unit II implies a relatively long dry season within the overall context of the warm and humid environment. Based on the Chemical Index of Alteration (CIA), the estimated land surface temperature during the Early Pleistocene (27 °C) was much higher than today (21.9 °C). Our results are consistent with previous environmental reconstructions based on vertebrate paleontological and isotopic studies of the *Gigantopithecus* fauna in southern China that the environment during the Early Pleistocene was warmer and more humid than today.

1. Introduction

The Pleistocene *Gigantopithecus* faunal complex of southern China is named after *Gigantopithecus blacki*, by far the largest primate ever to have roamed the earth (Ciochon et al., 1996). Three fragmentary mandibles and an abundance of isolated teeth of *Gigantopithecus blacki* have been uncovered from a dozen localities from southern China to northern Vietnam, suggesting a somewhat limited geographic range (Fig. 1). Previous studies of these *Gigantopithecus* faunal collections have primarily focused on taxonomic identifications (e.g., Pei and Woo, 1956; Woo, 1962; Zhang et al., 1973, 1975; Xu et al., 1974; Ciochon et al., 1996; Zheng, 2004; Zhao et al., 2006; Wang et al., 2007a,b; Jin et al., 2008; Zhao et al., 2008; Wang, 2009; Wang et al., 2014; Zhang et al., 2014), biostratigraphic correlations (Jin et al., 2009; Zhao and Zhang, 2013; Jin et al., 2014), and paleomagnetic and absolute geochronology (Rink et al., 2008; Shao et al., 2014, 2015; Sun et al., 2014). However, little research has discussed the paleoenvironmental background in which the *Gigantopithecus* fauna lived (but see recent studies by Zhao et al., 2011; Zhao and Zhang, 2013; Qu et al., 2014).

Fortunately, cave sediments have been used to evaluate paleoenvironmental change at Quaternary sites across the Old World. For instance, investigation of clay mineralogy of the La Chauverie karst deposits (Charente, SW France) indicated that cave sediments can be used to assess paleoclimatic and paleoenvironmental dynamics at the local scale (Albani et al., 2011). Within China, the geochemical composition of the Early Pleistocene Dongdong cave sediments in Zhoukoudian, Beijing, resulted in the identification of three cold

* Corresponding author.
** Corresponding author.
E-mail addresses: honghl8311@aliyun.com (H. Hong), cjbae@hawaii.edu (C.J. Bae).

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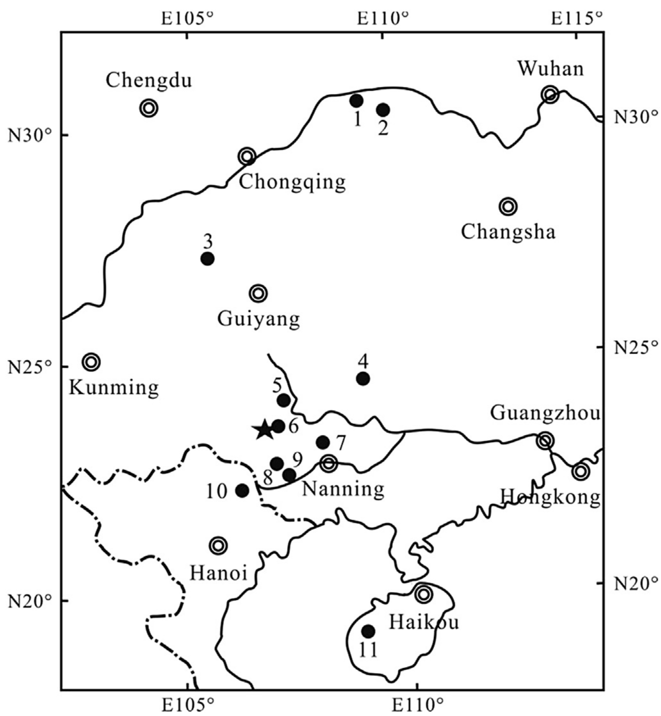

Fig. 1. Location of Mohui Cave (black star) with the distribution of *Gigantopithecus blacki* localities, modified from Zhao and Zhang (2013). 1, Longgupo; 2, Longgudong; 3, Baeryan; 4, Liucheng; 5, Bama; 6, Chuifeng; 7, Wuming; 8, Daxin; 9, Sanhe; 10, Than Khuyen; 11, Xinchong.

and dry events corresponding to the L26, L15, and L13 loess stages (Wang and Cheng, 2008). Nevertheless, no paleoenvironmental study based on clay mineral composition and geochemical characteristics of the sediments of the caves in which *Gigantopithecus* faunas have been found has been conducted. Here, we present the results of a sedimentological study of the Early Pleistocene deposits in Mohui Cave.

Mohui Cave (23°34′53″ N, 107°00′8″ E), located in the southeastern part of the Bubing Basin in Guangxi Zhuang Autonomous Region, is one of the most important Early Pleistocene sites because of the presence of *Gigantopithecus blacki* and an abundance of associated mammal fossils (Wang et al., 2007a). Details of the excavation, faunal composition and biostratigraphy, ESR and U-series dating of this cave can be found elsewhere (e.g., Wang et al., 2007b, 2014; Shao et al., 2015). Because of the thick sedimentary deposits that are close to three meters deep, Mohui Cave provides a snapshot of the Early Pleistocene environment of the region. Based on the analysis of clay minerals and major element composition of the deposits in Mohui Cave, we discuss the Early Pleistocene paleoenvironmental background of the *Gigantopithecus* fauna in southern China.

2. Materials and methods

2.1. Materials

The samples for clay minerals and major elements analyses were collected from a 2.8 m deep excavation profile in Mohui Cave (Fig. 2). The exposed stratigraphic section was carefully cleaned prior to sampling. Twenty five samples were taken at 10 cm intervals from a depth of 10 cm to the bottom of the profile. Each sample was about 500 g.

2.2. Methods

The clay minerals and major elements of the samples were analyzed in the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan). For clay minerals analysis, bulk samples were air-dried and then ground manually to powder using an agate mortar. The clay fraction (<2 μm) was isolated from the collected bulk sample by repeated suspension and centrifugation, and the oriented clay samples were prepared by carefully pipetting the clay suspension onto a glass slide. Ethylene glycol solvation treatment was performed in an electric oven at 65 °C for 4 h to determine the presence of smectite, mixed–layer illite–smectite, and mixed–layer kaolinite–smectite (Hong et al., 2007). The X-ray diffraction (XRD) patterns of powdered samples were recorded using a Rigaku D/Max-IIIA diffractometer, with Ni-filtered Cu Ka radiation (35 kV, 35 mA), 1°divergence slit, 1°anti-scatter slit, and 0.3 mm receiving slit. It measured from 3° to 65° 2θ at a scan rate of 4° 2θ/min and a step size of 0.02 2θ°. The determination of clay mineral types and calculation of their relative abundances follows the methods presented in Hong et al. (2010a, 2012).

For major elements analysis, about 100 g of each sample was ground to powder in an agate mortar, which was further dried at 105 °C for 2 h prior to measurement of loss-on-ignition and preparation of the fused pellets for X-ray fluorescence (XRF) analysis. The loss-on-ignition value was measured from the difference in weight between the sample heated to 1000 °C and to 105 °C. Major elements were measured by an XRF-1800 spectrometer. The analytical error is usually <1% and detection limit is <0.05 for most major elements. The weathering degree of the horizons was estimated from the Chemical Index of Alteration ("CIA") ($CIA = Al_2O_3/(Al_2O_3 + CaO^* + K_2O + Na_2O) \times 100\%$), where CaO^* refers to that in silicates and was calibrated using the method of McLennan (1993).

3. Results

The results of the XRD analysis of the clay minerals in Mohui indicate the sediment is primarily kaolinite (33.4% ~ 73.4%), followed by illite (13.3% ~ 45.3%), vermiculite (13.1% ~ 22.1%), and minor smectite (0% ~ 13.4%) (Table 1). The relative proportions of each clay mineral vary between different units (Fig. 2). Unit I is characterized by a complete absence of smectite along with a high percentage of kaolinite. Unit II, which yielded abundant mammalian fossils, had relatively high percentages of smectite and illite, with a relatively low kaolinite content. The clay mineral composition of Unit III is similar to Unit I, but characterized by relatively low smectite content.

The samples from Mohui show notable differences in major element abundances with great variations among the samples. Loss on ignition (LOI) is relatively high and also varies in a wide range from 2.83 to 21.06 wt%, suggesting that the LOI is dominated by carbonates and clay minerals. On average, the samples have relatively low SiO_2 content, with values of 18.27–33.37 wt%. The Al_2O_3 content is significantly high and show a narrow range from 18.54 to 33.69 wt%. The TiO_2 content of 0.90–1.76 wt% is notably high, reflecting intense chemical weathering. The CaO content displays a great deal of variation, ranging from 1.91 to 35.46 wt%. The difference in CaO concentration between the samples is clearly attributed to carbonate content, which is in agreement with the LOI values. The contents of mobile components Na_2O, K_2O, and MgO are significantly low and vary in a narrow range. Overall, the major element contents of the sediments in Mohui display rather noticeable variation throughout the profile, though their CIA values are high and relatively uniform, ranging from 91.35 to 97.97, with a mean of 95.61 (Table 2 and Fig. 3).