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Quaternary biostratigraphy in East Asia: A multidisciplinary research approach on *Gigantopithecus* fauna and human evolution

Gigantopithecus blacki, initially described by the German paleontologist G.H.R. Von Koenigswald (1935), is an extinct giant ape and a typical member of the Pleistocene fauna known from Oriental biogeographic zone (Southeast Asia, including southern China). There have been at least 16 *G. blacki* cave or fissure sites found in southern China and northern Vietnam, usually in association with hominin fossils and Paleolithic artifacts, all dating from the Early to Middle Pleistocene (Ciochon et al., 1996; Jin et al., 2014b; Zhang et al., 2014). Chow (1957) firstly named the *Gigantopithecus* faunal complex with an estimated age of Early Pleistocene, which was more primitive than the typical Middle Pleistocene *Ailuropoda-Stegodon* fauna (*sensu stricto*). Recently, the early Pleistocene fauna from southern China has been revised as the *Gigantopithecus-Sinomastodon* fauna based on the updated research about *Sinomastodon* (Gomphotheriidae, Proboscidea) (Wang et al., 2014).

Over the past decade, the most diverse and intriguing of *Gigantopithecus* and human remains with other vertebrate fossils have been discovered from the cave sites in Guangxi of southernmost China, especially from Chongzuo, along the China-Vietnam border. The systematic research from multidisciplinary perspectives on the progress of new discoveries from Chongzuo has been reported by a special volume "*Gigantopithecus* fauna" on Quaternary International (co-edited by Jin et al., 2014a: 354).

The present special volume, composed of a total of 18 papers, carries forward the achievements of the first one, and continues to report on the progress of new discoveries, not only from Chongzuo, Guangxi, but also from other areas of China, even eastern Asia (e.g., Chongqing, Nihewan basin, Guangdong, Shaanxi, Inner Mongolia, Shanxi, Bubing basin, and Thailand) that have important materials to offer.

These new discoveries included in this volume, and their subsequent analysis, provide invaluable information on *Gigantopithecus* fauna, human evolution, their geological and paleoenvironmental context, and the Quaternary biostratigraphic framework of eastern Asia.

The multidisciplinary nature of the research is reflected in the different aspects of contributions: faunal analyses, systematic paleontology and paleoanthropology, geochronology, Paleolithic archaeology, and paleoenvironmental reconstructions using data derived from stable isotopes and geochemical analyses of the deposits.

The first four papers lay stress on the new paleontological record both from southern and northern China. This volume begins with a detailed study on the mammalian fauna from Juyuan Cave of Boyue Mountain, Chongzuo, Guangxi based on a preliminary account by Jin et al. (2014b) and previously published paleomagnetic data of Sun et al. (2014). As Wang Y. et al. show in this paper, the large-primate fossil teeth collected from Juyuan Cave in Boyue Mountain can be identified as *Gigantopithecus blacki*. The Juyuan fauna associated with *G. blacki*, consisting of 45 mammalian species (such as *Sinomastodon yangziensis*, *Ailuropoda wulingshanensis*, *Stegodon huananensis*, and *Rhinoceros fusuiensis*), is a typical Early Pleistocene *Gigantopithecus-Sinomastodon* fauna of southern China. Combining the faunal analysis and magnetostratigraphic evidence, the Juyuan sediments can be best correlated with the Olduvai normal subchron, giving an estimated age of 1.8 Ma.

Zhu M. et al. described the new carnivore remains associated with *G. blacki* from the early Early Pleistocene Yanliang Cave, Chongzuo, Guangxi as *Megantereon microta* sp. nov., *Pachycrocuta licenti* and *Ursus thibetanus*. Especially, new specimens of *Megantereon* have been identified as a new species, *M. microta* based on morphological analysis. The *M. microta* is considered as the most primitive species in China during Pleistocene on dental characters.

Pang L.B. et al. present a systematic analysis of fauna from Migong Cave, an important Late Pleistocene fossil locality in Chongqing, the Three Gorges Area. Most of the mammals from Migong Cave are typical members of the "*Ailuropoda-Stegodon*" fauna from the Oriental Region, but also with several elements of the Palaearctic Region Pattern or the Monsoon Region Pattern. So it is concluded that during the period of the Migong Cave fauna, seasonal temperature difference was obvious, and the impact of the East Asian monsoon was relatively strong.

The Early Pleistocene *Sus lydekkeri* uncovered from several localities in northern China were fragmental. Liu W.H. et al. study a nearly complete skull of *Sus lydekkeri* recently uncovered at Yangshuizhan site in the Nihewan basin of northern China paleomagnetically dated 1.6 Ma. As the best preserved skull of *S. lydekkeri* so far, it bears some key characters for discussing the relationship between Asian *S. lydekkeri* and European *S. strozzii*.

The next set of contributions focuses on paleoanthropological research. Wei P.P. et al. build on previous studies of femoral morphology in Tianyuan 1 partial skeleton from Tianyuan Cave, Zhoukoudian of northern China by analyzing its diaphyseal structure using micro-computed tomography. Using several methods to acquire cranial capacities in modern humans and Pleistocene human crania, Wei P.P. et al. has got more reliable and more precise brain sizes for human fossils. Zhang Y.M. et al. compare several different methods to find a more accurate way of estimating cranial capacity of partial skulls and take a fragmentary Late Pleistocene cranium, Jingchuan 1 as an example. The results indicate that the cranial capacity estimates based on endocasts are more precise

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than those from exterior skull dimensions, that multivariate models are better than univariate ones.

The next group of papers presents new data on geochronology. The Black Cave in Guangxi was the first site yielding *G. blacki* teeth *in situ* in 1956. Shao Q.F. et al. carried out coupled ESR/U-series dating study of five Bovidae teeth from the upper layer and obtained a weighted mean age of 383 ± 20 ka for the mammalian fossils. This age estimate on fossil teeth is constrained by two 230Th/U ages of 404 ± 24 ka and 382 ± 9 ka obtained on speleothems formed below and above level of the mammalian fossils.

There have been sixteen *G. blacki* fossil teeth accompanied with abundant mammalian remains and stone artefacts unearthed from the Longgupo cave in Chongqing, China. Han F. et al. collected seventeen mammalian fossil teeth from different layers of unit C II and C III0 to conduct the combined ESR and U-series dating. The results show that the ages of teeth from unit C III0 of the north wall are about 2.35 Ma. The ages of samples from south wall give an average age of ~2.48 Ma. Compared with other early hominid settlements, Longgupo is one of the earliest evidences of hominid settlement in China and East Asia.

Zhiren Cave from Chongzuo is an important site for the study of the origin and the environmental background of early modern humans. Previous U-series dating of flowstone calcite has pinpointed an upper age limit for the fossils of about 100 ka. In order to achieve a better comprehension of the chronology of the modern human and contemporaneous faunal assemblage, the paleomagnetic, stratigraphic, and optically stimulated luminescence (OSL) dating methods have been applied to the cave sediments conducted by Cai Y.J. et al. In sum, the human remains and mammalian fauna from Zhiren Cave can be bracketed to 116–106 ka.

Panlong Cave in Guangdong Province is a hominin fossil-bearing site, lacking reliable chronological constraints for more than two decades. Tu H. et al. collected the flowstones and secondary calcite crystals for high-precision mass spectrometric U-series dating. The updated data indicate that the hominin fossils from Panlong Cave should be older than 441 ± 18 ka and may predate the nearby Maba Man.

With features associated with archaic *Homo sapiens* and evolved *Homo erectus*, the Dali skull from Shaanxi Province is a key fossil for understanding human evolution in China. Sun X.F. et al. combined a total of 12 samples in the sequence in the Dali Man site, and made use of the SAR Quartz OSL, TT-OSL and K-feldspar pIRIR290 dating protocols to date both the aeolian and fluvial deposits at the Dali Man site. The results showed that the age of the Dali Man was between 267.7 ± 13.9 ka and 258.3 ± 14.2 ka. Based on pollen analysis, Dali Man was proposed to live during a transitional time from glacial to interglacial during the S2/L3 and the MIS 7/8 stage.

The next four papers in this volume focus on Paleolithic archaeology. Wei G.B., Huang W.B. et al. report a newly-discovered Paleolithic site, Yumidong Cave in Chongqing which yielded a large number of animal fossils and lithic artifacts. The archaeological remains of Yumidong Cave were deposited during a long sequence from ca. 400 to 8 ka. The lithic assemblage was coherent and similar to mainland Southeast Asia with heavy, angular and massive stone tools made on pebble, cobble and without the Levallois, Discoid, and blade/bladelet phenomenon. To sum up, Yumidong Cave may represent clues of a potential local technological center of origin in unique technical world of Central-South China.

As the characteristic tool of the Acheulean industrial complex, Handaxes made of bone are much less common. Wei G.B., He C.D. et al. describe a bone handaxe from Chongqing, which represents the first bone handaxe ever discovered in China. The bone handaxe was manufactured from the mandible of an individual of *Stegodon orientalis*, which was dated to ~170 ka based on a U-series technique. This artifact represents the earliest evidence for a tradition of bone handaxe manufacture in East Asia.

Usewear analysis has become an essential method for studying function of lithic artifacts. In the paper by Chen H. et al., experiments and analyses of usewear on quartzite artifacts caused from bone-working was discussed based on the raw materials from the Wulanmulun Site, Inner Mongolia. Four working motions were involved and five specimens were selected for a multi-stage experiment which showed that the number of newly produced scars declined with time duration and intensity of usage. Chen H. et al. intend to establish a reference collection of lithic usewear on Chinese quartzite for archaeological analyses.

Yang S.X. et al. attempt to determine the source of the hornfels used to make the famous Late Middle Pleistocene lithic industry from Dingcun, Shanxi province. By combining geological mapping and geochemical fingerprinting (m-XRF), Yang S.X. et al. demonstrates that the source of the hornfels was around the Dagudui Mountain, 7 km east of Dingcun. The new geochemical data not only help to establish the source of the Dingcun industry, but also provide a reliable basis for the sub-classification of the hornfels that is more accurate than that resulting from visual inspection.

The last series of papers in the volume are concerning paleoenvironmental reconstructions. The goal of the study by Bocherens H. et al. is to evaluate the ecological flexibility of Asian Pleistocene apes, especially the giant form, *Gigantopithecus blacki,* using carbon and oxygen isotopic composition in tooth enamel of specimens from southern China and Thailand, together with coeval and extant mammalian taxa. The results support that *Gigantopithecus* was a forest-dweller with a generalist vegetarian diet. In southern China, *Gigantopithecus* lived in a forested environment, while in Thailand, it occupied only the forested part of a mosaic landscape including significant parts of open savannah. The carbon isotopic compositions of *Gigantopithecus* were very similar to those of orang-utans. Therefore, even when open savannah environments were present in the landscape, *Gigantopithecus* foraging was limited to forested habitats. The very large size of *Gigantopithecus*, combined with a relatively restricted dietary niche, may explain its demise during the drastic forest reduction that characterized the glacial periods in South East Asia.

Studies have shown that stable isotope composition of mammal tooth enamel can inform on a region's paleoclimate and paleoecology. Li D.W. et al. present the new results of the analysis of stable isotopes on a set of mammal tooth enamel from the late Middle Pleistocene Tantang Cave in Bubing Basin, Guangxi and compare them with other isotope data from nearby caves. The results of the oxygen isotope analysis indicate that the East Asia summer monsoon was stronger during the Tantang and Mohui mammal occupations and relatively weaker during the lifetime of the Sanhe mammals. The carbon isotope results from Tantang, Mohui and Sanhe overlap extensively suggesting these various faunas primarily lived in a closed forest environment.

In order to develop a firmer understanding of the paleoenvironment of *Gigantopithecus* fauna, there is still a relative paucity of data derived from other evidence besides taxonomic identifications. Huang S.M. et al. contribute to the 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. Based on the Chemical Index of Alteration (CIA), the estimated land surface temperature during the Early Pleistocene was much higher than today. These results are consistent with previous environmental reconstructions based on faunal analysis and isotopic studies of *Gigantopithecus* fauna in southern China.

In organizing the various papers that appear in this special volume, as well as a previous special volume of *Quaternary*

International co-edited by Jin et al. (2014a), it is clear that much new data and many original insights are coming out of the different regions of East Asia, especially China. This accumulation of new data and analyses is helping to increase our understanding of the Quaternary biostratigraphic framework of eastern Asia.

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