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A study of limestone from the Longmen Grottoes of Henan province, China by neutron activation analysis

Jian Zhu [a,b], Michael D. Glascock [c,*], Changsui Wang [a,b], Xiaojun Zhao [d], Wei Lu [e]

[a] Graduate University of the Chinese Academy of Science, Beijing, 100049, People's Republic of China
[b] The Joint Laboratory of Human Evolution and Archaeometry, Beijing, 100086, People's Republic of China
[c] Research Reactor Center, University of Missouri, 1513 Research Park Drive, Columbia, MO 65211, USA
[d] Luoyang Municipal Team for Cultural Relics, Luoyang, 47100, People's Republic of China
[e] Longmen Grottoes Research Institute, Luoyang, 471023, People's Republic of China

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ABSTRACT

The Longmen Grottoes, also known as the Longmen Caves or Dragon's Gate Grottoes, are located near the city of Luoyang, Henan province, China. The grottoes were carved into the limestone cliffs during the period from 493 AD to 1130 AD. Limestone samples from different areas within the grottoes were analyzed by neutron activation analysis (NAA) to determine the concentrations of major, trace and rare-earth elements (REEs). Three compositional groups were identified corresponding to different areas within Longmen Grottoes. X-ray diffraction (XRD) was performed on a few samples to obtain information about the mineral structure. The results indicate that rocks in the northern area are comprised of dolomite, while rocks in the middle and southern areas are comprised of limestone. The NAA results provide information useful for identifying and relocating fragments from the grottoes that may have lost their identity. The compositional data also provides important clues regarding the geologic history of the limestone formation at Longmen.

1. Introduction

For more than thirty years, chemical characterization has been used to obtain important evidence about the provenance of limestone artifacts. Analytical investigation of limestone by neutron activation analysis (NAA) began in the 1970s with a study by Meyers and van Zelst (1977). Following their success, other studies began using NAA to conduct research on limestone sculptures, monuments and quarries (Blum, 1994; French, 1991; Holbert et al., 2001; Holmes and Harbottle, 1994). Most of the research has been performed on limestone from French quarries and medieval sculptures by applying multivariate statistical methods to the trace element data in order to determine provenance for sculptures of uncertain origin. This information has allowed researchers to successfully assign sculptures to the regions or specific quarries that provided the limestone (Clark, 1994; French, 1994; Holmes et al., 1986).

From the 1970s through late 1990s, the Brookhaven National Laboratory analyzed more than 2000 quarry and sculpture samples. Data for each sample of limestone is recorded in a database of medieval sculptures (see http://www.limestonesculptureanalysis.com/). The database provides compositional "fingerprints" for limestone quarries that enables the provenance of sculptures to be determined by comparing new compositional fingerprints to these present in the database.

Previous NAA research has shown that limestone sources tend have unique chemical compositions and the data give significantly greater provenance information than petrographic analysis (De Vito et al., 2004; Holmes and Harbottle, 2003). Based on comparing the detailed compositions of the limestone sculptures, combined with traditional stylistic and iconographic analysis, one can determine the geographic origin of stones that have lost their histories or were looted. In some cases, it may also provide clues about the types and qualities of stone sought by the carver or mason, about workshop practices, and about the transport of raw material and finished pieces (Holmes and Harbottle, 2001).

This paper focuses on the compositional analysis of limestone from the Longmen Grottoes. The purpose of this paper is to summarize the compositional data for limestone from Longmen Grottoes by employing multivariate statistical methods. The results successfully demonstrate the utility of the technique for recognizing compositional differences between different parts of the

* Corresponding author.
E-mail address: GlascockM@missouri.edu (M.D. Glascock).

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mountain. Furthermore, it permits us to describe the locations within the grotto used by the artisans who carved Buddhist statues during different periods and to make possible the determining the origins of sculptures that have lost their identity.

Finally, trace element data can be used to estimate the paleo-environmental conditions establishing carbonate formations such as Longmenshan (Renard, 1986). The method typically involves comparisons to reference shales such as the Post-Archaen Australian Shales (PAAS) studied previously by Taylor and McLennan (1985). Recent articles by Armstrong-Altrin et al. (2003), Cullers (2002), and Nagarajan et al. (2011) illustrate the approach we employed in this work.

2. Historical background

Chinese stone sculpture, while differing greatly from its Western counterparts, has undergone a long process of development throughout history. Grotto limestone was an important type of the sculptural art in ancient China. Grotto limestone was generally hewed and carved in declining limestone rocks belonging to a larger mountain. Its height from the ground usually did not exceed 200 m and it was generally distributed in the cliffs along the side of a river (Zhou and Cao, 1996).

During the long periods of social and political upheavals in China, many sculptures suffered damage from looting, and fragments were dispersed to public and private collections around the world. As a result, their sources were often obscured by their removal from the cave in which they originated. Although there has been much research describing the styles and iconography of Chinese limestone grottoes, compositional investigations are quite rare and provenance research has been absent until now.

One of the most famous art sculptures among China's sculptured groups is the Longmen Grottoes, located 12 km south of the historic city of Luoyang in western Henan province of central China. See Fig. 1. The Longmen Grottoes were approved for inclusion to the List of World Cultural Heritage by the 24th UN Heritage Commission on November 30, 2000.

The Longmen Grottoes has some 1350 caves and 40 Buddhist pagodas carved out of the hard limestone cliffs (McNair, 2007). Two hills, Xiangshan on the east and Longmenshan on the west, flank the Yi River forming a valley. The grottoes are located along a 1 km stretch of this river and were carved in the steep slopes to create the famous "Longmen Caves" shown in Fig. 2. A total of 2345 niches or grottoes have been recorded on both sides of the river. Ancient craftsman created more than 100,000 Buddhist statues and about 2500 stelae and inscriptions. Approximately 90% of the work took place on the western bank. Many of the statues were carved elsewhere and moved into the caves later.

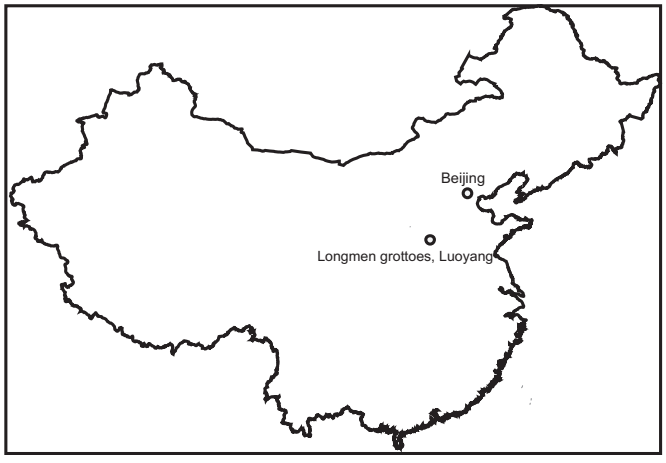

Fig. 1. Map of China showing the location of Longmen Grottoes near Luoyang in Henan province. Map of China showing the location of Laoyang.

Construction of the Longmen Grottoes was strongly influenced by the Dynastic Period and the geologic characteristics of the limestone. Construction of the Longmen Grottoes began in 493 AD during the reign of Emperor Xiaowen, Northern Wei Dynasty and continued through six successive dynasties, including the Tang and Song, for a span of more than 400 years.

The Longmen Grottoes are separated into three zones (i.e. north, middle, and south) as shown in Fig. 2. The northern zone ranges from the Qianxi temple to Moyansan statues, and it contains few rock fractures and huge strata thickness. The middle zone extends from Wanfodong to Huoshaodong. These two zones are the part of the main grottoes and they contain most of the caves and statues. The southern zone extends from Huoshaodong to Jinandong. The presence of a rupture section and smaller spaces between the layers of rock made the southern zone less suitable for carving. Due to the poor quality of the limestone, workers were forced to discontinue their work and this resulted in a large number of empty caves in the southern zone.

3. Geological setting

The Longmenshan formation in which the Longmen Grottoes were carved was formed during the Cambrian period (~500 Ma). The current hills were formed from calcite and dolomite deposited during a time when the region existed as a shallow sea. During the Mesozoic, the region began to rise along with an accompanying volcano such that a fault appeared. The fault plane is located along the base of the Longmen Mountains with an orientation of approximately northeast. During the Cenozoic, a number of earthquakes occurred in the region and motion of the fault caused an uplifting of the Longmen Mountains relative to the Sichuan Basin located on the east.

4. Materials and methods

4.1. Samples

Because most of the caves and statues are located in Longmenshan, on the western side of the river, all sampling for this project was performed there. Samples were collected from each of the three areas mentioned above. Most of samples were removed from surrounding rock located near the statues or caves. It was verified that the samples were collected close to the grottoes by visual inspection. Because some repair work was taking place in the southern zone during the sampling period, a larger number of samples were collected there. A total of 69 samples were collected from all parts of Longmen Grottoes.

4.2. Neutron activation analysis

The limestone samples were prepared for neutron activation analysis (NAA) using standard procedures employed at the University of Missouri Research Reactor (MURR). Clean interior fragments of about 1 cm^3 (i.e. 2.5 g) were removed from each rock specimen and ground into a powder with an agate mortar and pestle to homogenize the samples. The powdered samples were transferred to clean glass vials and placed in a drying oven overnight at 105 °C prior to weighing. Archival portions were retained from each specimen for future research.

Two analytical samples were prepared from each specimen. Portions weighing approximately 150 mg were weighed into clean