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Original article

The North China Steptoean Positive Carbon Isotope Event: New insights towards understanding a global phenomenon☆

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ABSTRACT

Precise biostratigraphic correlation of the base of the Paibian Stage, Cambrian, within and beyond the North China craton has been difficult, mostly because of the strong endemism of the trilobite fauna on the shallow platform facies. The use of the Steptoean Positive Carbon Isotope Excursion (SPICE) in defining the Guzhangian-Paibian stage boundary has become a standard practice. Thus, a chemostratigraphic study of the Huangyangshan section from North China has been carried out. This section in Shandong Province clearly records the SPICE, with the most detailed fossil and carbonate carbon isotope data to date. Compared to other sections in the world, all the published SPICE in North China display both reduced peak and reduced difference ($\Delta^{13}C$) values. These may imply unique conditions on the North China craton during the upper Guzhangian to Paibian stages. This study shows that the SPICE is recorded in relatively condensed sections in North China; thus, $\leq$ 0.5 m sampling density is suggested here in order to evaluate the presence of the SPICE in North China and condensed sections.

1. Introduction

Despite more than a century of research, the challenge of a precise global correlation of the base of the Paibian Stage (Peng et al., 2004) remains unresolved in North China (Ng et al., 2014). However, the use of the onset of the Steptoean Positive Carbon Isotope Excursion (SPICE) in defining this boundary has been successful for global correlation (Saltzman et al., 1998, 2000, 2004; Peng et al., 2004, 2012; Álvaro et al., 2008; Kouchinsky et al., 2008; Sial et al., 2008; Ahlberg et al., 2009). Although the SPICE is widely used in correlation, it has been little studied on the North China platform. Up to now, all the available data on the SPICE in North China (Zhu et al., 2004; Du et al., 2007; Ng et al., 2014; this study) indicate that the SPICE signals may not have been completely preserved in every section in North China, because of the shallow water setting. Therefore, the questions are: How to identify the SPICE in North China? And how to use it in fine-tuning the global correlation scheme? This paper addresses these questions by using carbonate carbon isotope data from the Huangyangshan (HYS) section in North China, a section spaning the Guzhangian-Paibian transition, and discusses the possible implications for SPICE-related studies in North China.

2. Geological background and previous studies

The formal study of Cambrian geology and paleontology in North China started in the late 19th and early 20th centuries (e.g., Dames, 1883; see Peng, 2007). Willis (1907) and Blackwelder (1907) systematically sampled the Cambrian fossils, and established the fundamental stratigraphy. Subsequently, Walcott (1905, 1911, 1913) studied their fossil collections, and published the first records of the Cambrian paleontology for the area. After working on the traditional North China stratigraphy, Sun (1924, 1935) proposed the basic framework and stratigraphic units. In spite of many studies of various aspects of the geology and paleontology of the North China craton since the 1940s (e.g., Howell, 1947; Lu and Dong, 1952; Lu et al., 1982; Zhang and Jell, 1987, Zhang, 1988, 1999; Zhu and Wittke, 1989; Guo and Zhang, 1992; Qian, 1994; Guo et al., 1996; Zhang, 2003; Duan et al., 2005; Bagnoli et al., 2014), there is still no precise correlation scheme for the North China craton, and particularly imprecise for the base of the Paibian Stage (Peng, 2009a, 2009b). In a recent work, Yuan et al. (2012) provided numerous new fossil data from the Changhia (= Zhangxia) Formation and part of the Kushan (= Gushan) Formation in Shandong Province, North China. These authors also established

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new regional stratigraphic units, and suggested a new Jinanian Stage in the North China platform (shallow-water facies), which approximately correlates with the global Guzhangian Stage. More recently, Ng et al. (2014) provided new data from the type locality of the Changshan Formation, name-bearer of the North China Changshanian Stage, in Tangshan, Hebei Province, demonstrating the existence of the SPICE event in North China. The onset of the SPICE event is used to approximate the base of the Paibian Stage in North China. Moreover, Bagnoli et al. (2014) defined the base of the Paibian in Shandong Province by the First Appearance Datum (FAD) of the conodonts *Furnishina longibasis* and *F. quadrata*, which is below the FAD of *Chuangia* in their section, and also slightly below the onset of the SPICE. Ng et al. (2014) summarized the commonly used biozonal schemes on the North China craton, and demonstrated that the use of the FAD of *Chuangia* Zone to approximate the base of the Paibian Stage may be still the most practical way to identify this horizon in the field. Peng (2009a, 2009b) argued that this boundary should be located within the *Prochuangia-Paracoosia* Zone, as there is a small gap between the FADs of *Chuangia* and *G. reticulatus* in the GSSP section in Hunan, China.

3. Material and methods

The Huangyangshan (HYS) section is in Shandong Province, North China, about 15 km southeast of the city of Laiwu (Fig. 1(A)), close to Niumazhuang village, and on a southwest-facing slope about 200 m east of the eastern edge of Hulushan Reservoir (Fig. 1(B)). The GPS position is N36°06′00.6″, E117°47′07.2″. This section is mostly composed of oolitic limestone, wackestone, mud limestone, and flat-pebble conglomerate (= edgewise limestone/calcirudite; Myrow et al., 2004) with micritic intraclasts (Figs. 1(C, D), and 2). Thin interbeds of calcareous siltstone and mudstone are also common. The depositional environment was shallow marine with frequent storms (Zhou et al., 2011). Fossils are mostly concentrated in 1–3 cm-thin beds of coarser-grained bioclastic grainstone, packstone, and wackestone horizons. Disarticulated trilobites and linguliform brachiopods are commonly found, with occasional agnostids. The relatively abundant fossil content allows us to establish the basic biostratigraphic framework in this section. The abundant limestone strata provide excellent intensive sampling materials for carbonate carbon and oxygen isotope testing.

The HYS section has no geological evidence of any obvious hydrothermal event or hydrothermal diagenesis. There are very small-scale calcite veins in few horizons. Most of the isotope samples were from micritic limestone and wackestone layers: light grey to light yellowish-brown, fine-grained, thin-bedded, without calcite vein (Fig. 1(C, D)). They do not seem to be particularly rich in organic carbon. Isotope samples in flat-pebble conglomerate were collected only from intergranular micritic matrix. For carbonate

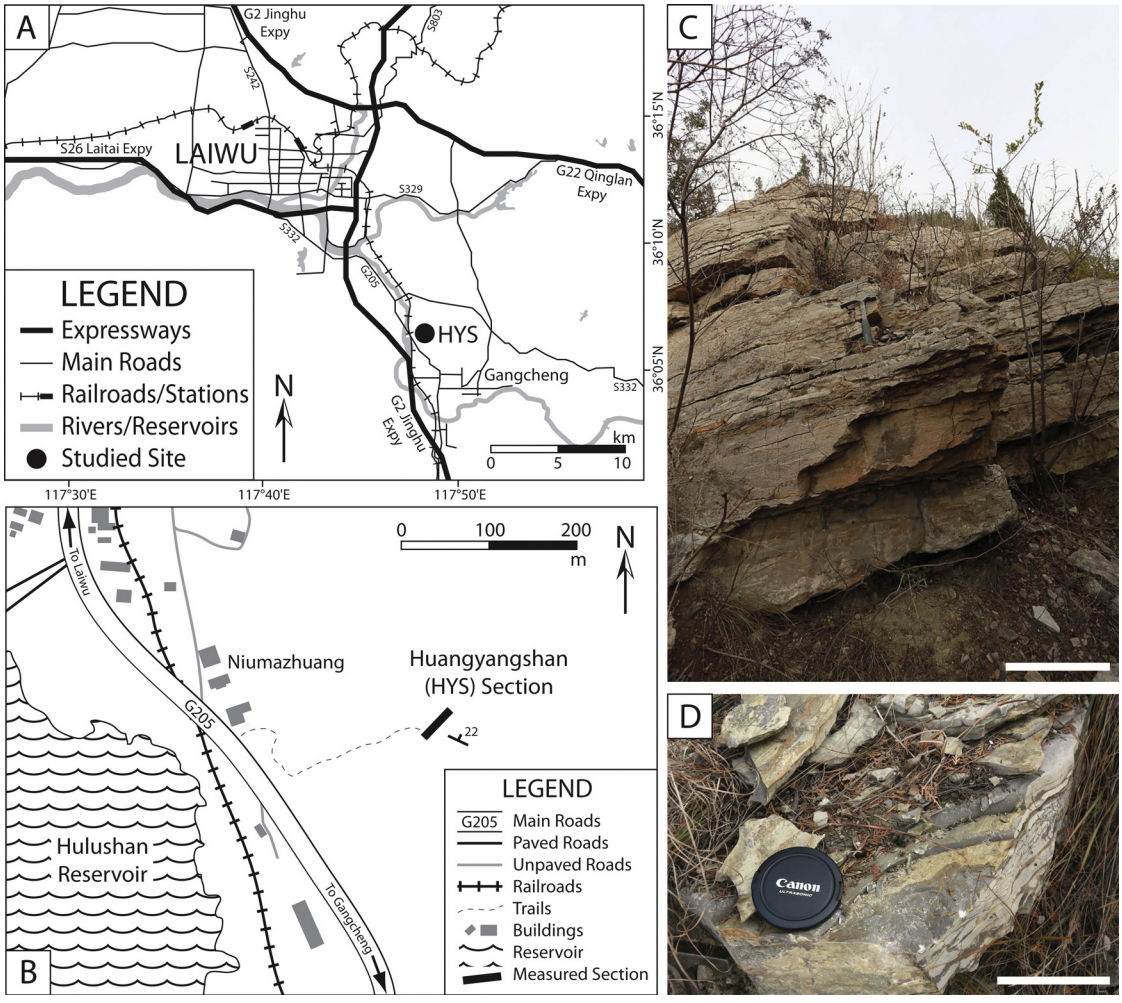

Fig. 1. Locality map of the Huangyangshan (HYS) section in the Laiwu area, Shandong Province, North China. **A**. Geographical location of the HYS Section. **B**. HYS section location near Niumazhuang. **C**. Outcrop photograph of the thick limestone ledge (about −1 to 2 m) in the HYS section; scale bar: 50 cm. **D**. Whole-rock carbonate samples were collected from light-grey, fine-grained, and thin-bedded micritic limestone and wackestone horizons; scale bar: 10 cm.