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Reconstructing Late Paleozoic exhumation history of the Inner Mongolia Highland along the northern edge of the North China Craton

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ABSTRACT

The Inner Mongolia Highland (IMH), along the northern edge of the North China Craton, was considered to be a long-standing topographic highland, whose exhumation history remains elusive. The aim of this study is to reveal Late Paleozoic exhumation processes of the IMH based on an integrated analysis of stratigraphy, petrography of clastic rocks, and U–Pb ages and Hf isotopes of detrital zircons from Permian–Triassic succession in the middle Yanshan belt. The results of the study show that the Benxi Formation, which was originally regarded as a Late Carboniferous unit, proves to be Early Permian in age because it contains detrital zircons as young as ~298 Ma. The Lower Shihezi Formation is demonstrated to be a unit whose age spans the boundary of the Middle and Upper Permian, constrained by a U–Pb age of 260 ± 2 Ma from a dacite layer. Clastic compositions of conglomerate and sandstone change markedly, characterised by the predominance of sedimentary components in the Benxi–Shanxi Formations, by large amounts of volcanic clastics in the Lower and Upper Shihezi Formations, and by the presence of both metamorphic and igneous clastics in the Sunjiagou–Ermaying Formations. Sedimentary clastics include chert, carbonate, sandstone and quartzite, which may have been derived from Proterozoic to Lower Paleozoic sedimentary covers. Volcanic clasts were directly related to volcanic eruptions, while granite and gneiss grains were sourced from exhumed Late Paleozoic intrusive rocks and basement rocks. Detrital zircon U–Pb ages can be divided into five populations: 2.6–2.4 Ga, 1.9–1.7 Ga, 400–360 Ma, 325–290 Ma and 270–250 Ma. Precambrian detrital zircons are typically subrounded to rounded in shape, implying a recycling origin. Late Paleozoic zircons show oscillatory zones and their Th/U ratios >0.4, suggesting a magmatic origin. Most Phanerozoic zircons have negative $\varepsilon_{Hf}(T)$ values of −3.2 to −25.5, which are compatible with those of Late Paleozoic plutons in the IMH. The results indicate that the IMH may have been covered with Proterozoic to Lower Paleozoic sedimentary strata, which then underwent subsequent erosion and served as provenances for adjacent Late Paleozoic basins. Vertical changes in both clastic compositions and detrital zircon ages in Permian–Triassic strata imply an unroofing process of the IMH. Three phases of the IMH uplift are distinguished. The first-phase uplift commenced 325–312 Ma and resulted from magmatic intrusion related to southward subduction of the Paleo-Asian Ocean. The second-phase uplift took place in the Middle Permian and may be attributed to crustal contraction related to the collision of the North China Craton and the Southern Mongolia terrane. The third-phase uplift happened at the end of the Permian, and may have been induced by upwelling of calc-alkali magma under an extensional setting.

1. Introduction

The North China Craton (NCC) is bounded by the Central Asian Orogenic Belt (CAOB) to the north and the Qinling-Dabie Belt to the south (Fig. 1). The northern margin of the NCC consists of exposed Precambrian crystalline basement rocks, which were formed by Archean–Paleoproterozoic crustal building (Santosh et al., 2013; Zhai et al., 2011; Zhao et al., 2005). This strip of basement terrain is called the Inner Mongolia Highland (IMH) in Chinese literature and was previously regarded as a long-standing highland since Proterozoic times (HBGMR, 1989; Huang, 1954). Recent studies show that the uplifting and exhumation of the IMH commenced in the Late Paleozoic and were influenced by subduction, closure

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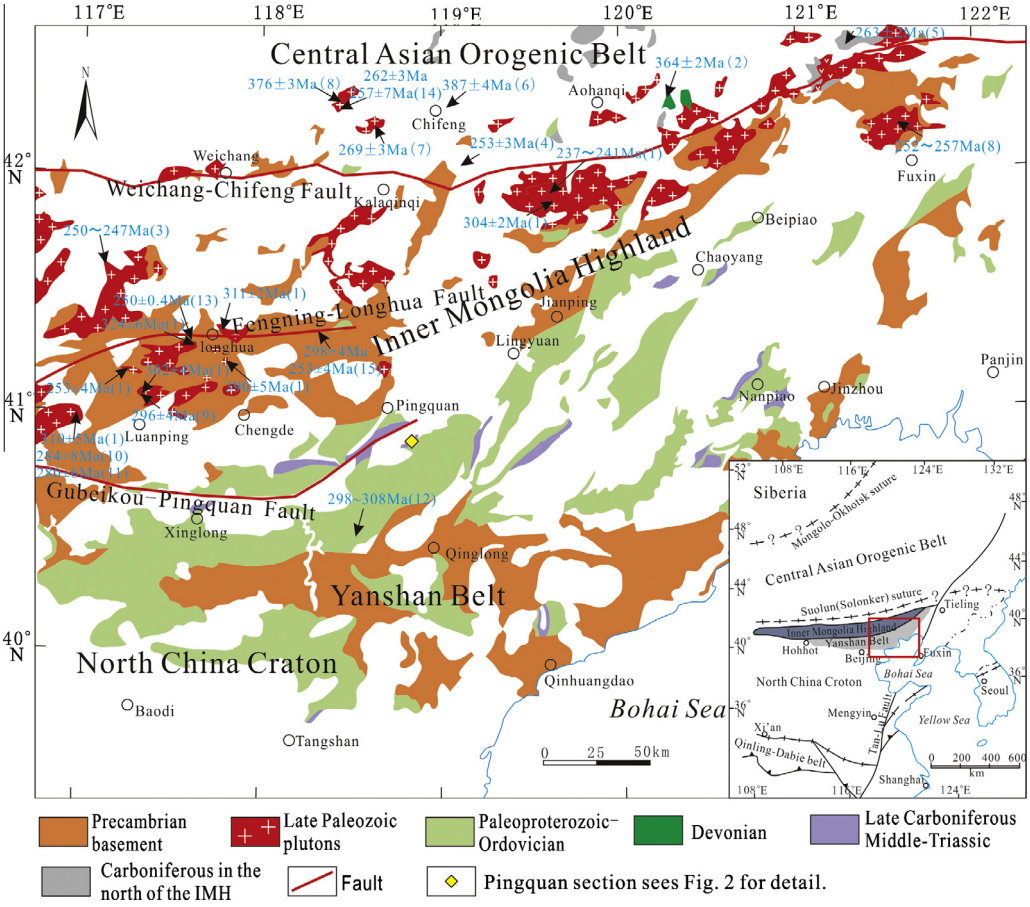

Fig. 1. Simplified geological map showing distribution of Upper Carboniferous to Middle Triassic strata. The inset is modified after Davis et al. (2001), showing the tectonic setting of the northern North China Craton. Age data of magmatic rocks are from the following studies: 1—Zhang et al. (2009), 2—Zhang et al. (in press), 3—Mao et al. (2003), 4—Davis et al. (2001), 5—Ma (2011), 6—Shi et al. (2010), 7—Liu et al. (2010), 8—Zhang et al. (2012b), 9—Ma et al. (2012), 10—Ma et al. (2004), 11—Wang et al. (2007), 12—Zhao et al. (2007), 13—Zhou (2009), 14—Shao et al. (2012); 15—Zhang et al. (2014).

of the Paleo-Asian Ocean and intraplate deformation (Davis et al., 2001; Wang et al., 2013; Windley et al., 2007; Xiao et al., 2003). Paleogeographic reconstructions show that the IMH may have been covered with thick sedimentary rocks. Similar Proterozoic strata up to 3500 m thick are present across the highland (Meng et al., 2011; Meng and Ge, 2004). Emplacement depths of plutons, estimated from aluminm-in-hornblende geobarometry, indicate that the IMH underwent significant denudation from Late Carboniferous to Early Jurassic times and that approximately 15-km upper-crustal materials were eroded away (Zhang et al., 2007; Zhang and Zhao, 2013). The Mesozoic exhumation was explicitly confirmed by structural deformation (Davis et al., 2001; Wang et al., 2013) and sedimentary records (Liu et al., 2012; Xu et al., 2013b), and was attributed to post-orogenic mantle upwelling (Zhang et al., 2012a, 2014) and intraplate south-vergent overthrusting (Davis et al., 2001; Wang et al., 2013; Zhao, 1990).

Controversy still remains about the mechanisms and processes of Late Paleozoic exhumation of the IMH. Due to the occurrence of coeval intrusions, it has been proposed that the northern NCC became an Andes-type active continental margin during Late Carboniferous to Early Permian times (Jian et al., 2010; Wang and Liu, 1986; Windley et al., 2007; Xiao et al., 2003; Zhang et al., 2009). The continental arc magmatism and the final closure of the Paleo-Asian Ocean likely account for the uplifting of the IMH (Lin et al., 2013; Zhang and Zhao, 2013). It is also argued that Early Permian volcanism along the northern NCC resulted from post-orogenic extension (Luo et al., 2009; Shao et al., 2012; Zhang et al., 2011) and that the closure of the Paleo-Asian Ocean occurred prior to the Permian (Shao, 1991; Tang, 1990; Xu et al., 2013a).

Some studies have documented that the NCC basin was sourced from the IMH in the Late Paleozoic (Cope, 2003; Li et al., 2010; Yang et al., 2006). Therefore, its basin-fill could provide important age constraints on the tectonic evolution of the IMH. In this study, a detailed analysis of the provenance of Late Carboniferous–Middle Triassic succession in the Yanshan belt was conducted (Fig. 1). The results of detrital zircon geochronology, in conjunction with Hf isotopes and framework petrography, demonstrated that the IMH at the northern margin of the NCC had experienced a three-phase uplift since the Carboniferous.

2. Tectonic setting

The study area is located in the middle Yanshan belt, south of the IMH along the northern margin of the NCC (Fig. 1). The Yanshan belt is a Mesozoic tectonic province that developed the same sedimentary covers that were present over the entire NCC before the Middle Triassic (Davis et al., 2001; Wang et al., 2013; Zhao, 1990). The sedimentary covers include Meso–Neoproterozoic carbonate and clastic rocks, Cambrian–Ordovician carbonate and Late Carboniferous to Middle Triassic clastic rocks. To the north of the IMH runs the CAOB, which is a result of both southward and northward subduction and the accretion of the Paleo-Asian Ocean in the Paleozoic (Windley et al., 2007; Xiao et al., 2003).