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# Geophysical and geological tests of tectonic models of the North China Craton

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ABSTRACT

The geometry and timing of amalgamation of the North China Craton have been controversial, with three main models offering significantly different interpretations of regional structure, geochronology, and geological relationships. One model suggests that the Eastern and Western Blocks of the NCC formed separately in the Archean, and an active margin was developed on the Eastern Block between 2.5 and 1.85 Ga, when the two blocks collided above an east-dipping subduction zone. A second presumes the Eastern Block rifted from an unknown larger continent at circa 2.7 Ga, and experienced a collision with an arc (perhaps attached to the western block) above a west-dipping subduction zone at 2.5 Ga, and the 1.85 Ga metamorphism is related to a collision along the northern margin of the craton when the NCC joined the Columbia supercontinent. A third model suggests two collisions in the Central Orogenic Belt, at 2.1 and 1.88 Ga, but recognizes an early undated deformation event. Recent seismic results reveal details of the deep crustal and lithospheric structure that support both the second and third models, showing that subduction beneath the Central Orogenic Belt was west-directed, and that there is a second, west-dipping paleosubduction zone located to the east of the COB dipping beneath the Western Block (Ordos Craton). The boundaries identified through geophysics do not correlate with the boundaries of the Trans-North China Orogen suggested in the first model, and the subduction polarity is opposite that predicted by that model. High-pressure granulite facies metamorphism at 1.85 Ga is not restricted to the "TNCO" as suggested by the first model, but is documented across the NCC, as predicted by the second model, suggesting a major continent–continent collision along the north margin of the craton at 1.85 Ga. Further, it has recently been shown that in the southern "TNCO", there is no record of metamorphism at circa 1.85 Ga, but only at 2.7–2.5 Ga, showing that the "TNCO", as defined as a circa 1.85 Ga orogen, does not exist. This is further confirmed by recent Re–Os isotopic studies which show that the subcontinental lithospheric mantle beneath the southern COB is late Archean in age, and that a province in the northern NCC is circa 1.8 Ga, correlating with the proposed collision belt of the NCC with the Columbia supercontinent across the entire NCC. The COB is an Archean convergent belt, re-worked in the Paleoproterozoic, and the Paleoproterozoic tectonism is widespread across the NCC, as predicted by the model whereby the previously amalgamated Eastern and Western Blocks experienced a continental collision with Columbia at circa 1.85 Ga, but uplift/exhumation rates are slow, necessitating a re-evaluation of the tectonic models of the NCC.



## 1. Introduction: Precambrian geology of the North China Craton

The Archean North China Craton (NCC) occupies about 1.7 million km$^2$ (Fig. 1) in northeastern China, Inner Mongolia, the Yellow Sea, and North Korea (Bai and Dai, 1996, 1998). It is bounded by the Qinling–Dabie Shan Orogen to the south, the Yinshan–Yanshan Orogen to the north, the Longshoushan Belt to the west and the Qinglong–Luznxian and Jiao–Liao Belts to the east (Bai and Dai, 1996; Kusky et al., 2007a; Li et al., 2007, 2009, 2010a). The craton consists of two major blocks, separated by the Central Orogenic Belt (e.g., Zhao, 2001; Zhao et al., 2001a, 2001b, 2002, 2005; Kusky et al., 2001; 2004a, 2004b; 2007a, 2007b; Kusky et al., 2007b). Major rock types include circa 3.8–2.5 Ga gneiss, tonalite–trondhjemite–granodiorite (TTG), granite, migmatite, amphibolite, ultramafic bodies, mica schist, dolomitic marble, graphite- and sillimanite-bearing gneiss (khondalite), banded iron formation (BIF), and meta-arkose (Jahn and Zhang, 1984a,b; Bai et al., 1992; Wu et al., 1998; Jahn et al., 1987; Bai, 1996; He et al., 1991, 1992; Wang et al., 1997). The Archean rocks are overlain by quartzites, sandstones, conglomerates, shales, and carbonates of the 1.85 to 1.40 Ga Mesoproterozoic Changcheng (Great Wall) Series (Li et al., 2000a, 2000b). In some areas of the central part of the NCC, 2.40 to 1.90 Ga Paleoproterozoic sequences that were deposited in cratonic graben are preserved (Kusky and Li, 2003).

The North China Craton is divided into two major blocks (Eastern and Western Blocks) but the boundaries and ages of the intervening orogen have been the subject of some recent debate. One group (e.g.,

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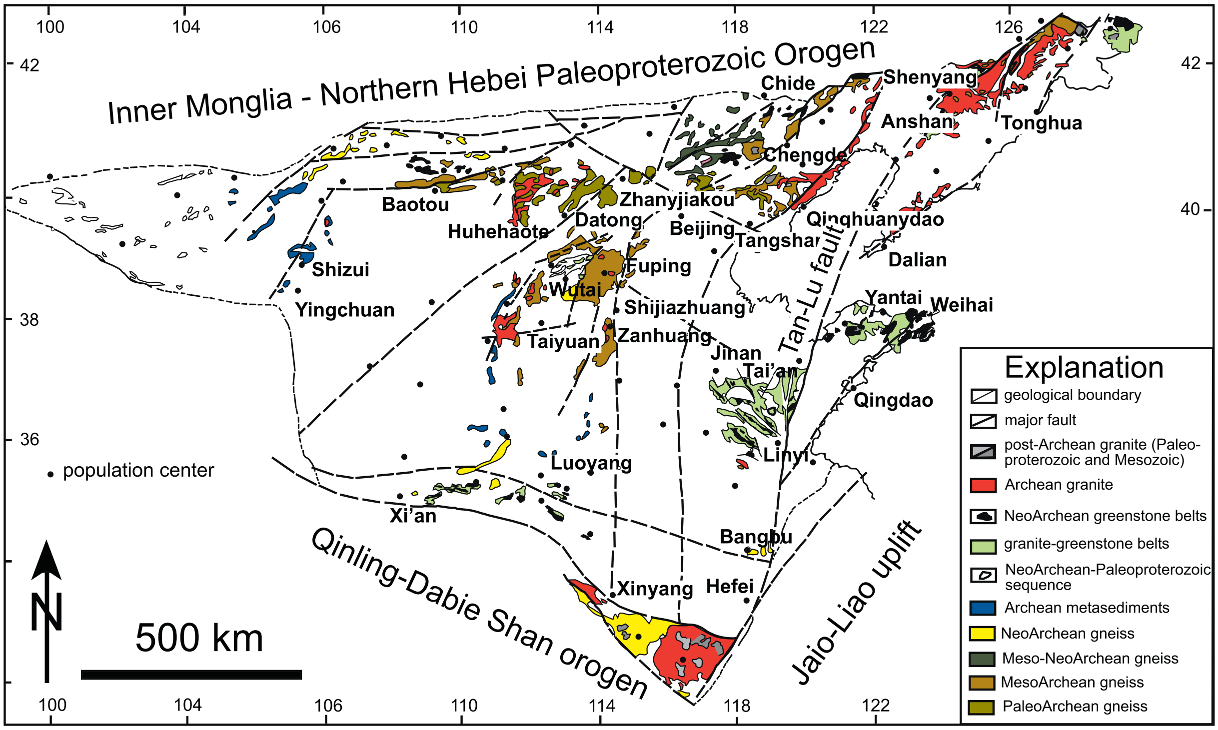


**Fig. 1.** Geological map of the North China Craton (from Kusky and Li, 2003).

Kusky et al., 2001, 2004a, 2004b, 2007a, 2007b; Kusky and Li, 2003; Kusky and Santosh, 2009).) suggests that the boundary is a Late Archean – Paleoproterozoic orogen called the Central Orogenic Belt (COB), that suffered later deformation at c.a. 1.85 Ga. The other group (e.g., Zhao et al., 2001a) suggests that the orogen is a c.a. 1.85 Ga feature called the Trans-North China Orogen (TNCO) that represents collision of the two blocks at 1.85 Ga. It should be noted that the COB differs from the Trans-North China Orogen (TNCO) as defined by Zhao et al. (2001a). The COB is an Archean orogen, with Archean structures defining its boundaries, whereas the TNCO is defined as a Proterozoic orogen, albeit one bound by Mesozoic structures. The Precambrian geology on either side of these Mesozoic faults is remarkably similar, with the only clear distinction between rocks inside and outside of the so-called "TNCO" being Zhao et al.'s definition of "exposed and unexposed Archean to Paleoproterozoic basement in the TNCO, and exposed and unexposed Archean to Paleoproterozoic basement in the eastern and western blocks." In this review we assess these different models for the tectonic evolution of the North China Craton in the light of new geophysical and geochemical data, and present a unified model that is consistent with the new data and geological relationships in the craton. The Eastern and Western Blocks are separated by an orogenic belt (COB, or TNCO) in which nearly all U–Pb zircon ages (upper intercepts) fall between 2.55 and 2.50 Ga (Zhang, 1989; Zhao et al., 1998, 1999a, 1999b, 2000, 2001a, 2001b, 2005; Kröner et al., 1998, 2002; Li et al., 2000b; Wilde et al., 1998; Zhao, 2001; Kusky et al., 2001; Kusky and Li, 2003; Kusky et al., 2004a, 2004b; Polat et al., 2005, 2006a,b). The stable Western Block, also known as the Ordos Block (Bai and Dai, 1996; Li et al., 1998), is a stable craton with a thick mantle root, no earthquakes, low heat flow, and a lack of internal deformation since the Precambrian. The Western Block contains a thick platformal sedimentary cover intruded by a narrow belt of 2.55 to 2.50 Ga arc plutons along its eastern margin. Much of the Archean geology of the Western Block is poorly exposed because of thick Archean to Cretaceous platformal cover.

In contrast, the Eastern Block is atypical for a craton in that it is tectonically active and has numerous earthquakes, high heat flow, and a thin lithosphere reflecting the lack of a thick mantle root (e.g., Zhai et al., 2007). The Eastern Block contains a variety of ca. 3.80 to 2.50 Ga gneissic rocks and greenstone belts locally overlain by 2.60 to 2.50 Ga sandstone and carbonate units (Kusky and Li, 2003). Deformation is complex, polyphase, and indicates the complex collisional, rifting, and underplating history of this block from the Early Archean through the Meso-Proterozoic (Zhai et al., 1992, 1995, 2002, 2010; Li and Kusky, 2007; Kusky et al., 2001; Kusky and Li, 2003; Kusky et al., 2004a, 2004b; Zhai, 2004, 2005; Polat et al., 2006a, 2006b), and again in the Mesozoic-Cenozoic (Zhai et al., 2007; Zhang et al., 2011).

## 2. Summary of tectonic models of the North China Craton

For the past decade there has been a controversy over the Precambrian tectonic evolution of the North China Craton, with two main models dominating the controversy, and the recent introduction of two new alternative models in the past few years. Stimulated by funding from the "North China Interior Structure Project" of the Chinese National Natural Science Foundation, new seismic reflection and tomographic profiles have been completed across various tectonic belts of the craton. The results of these geophysical surveys shed new light on the tectonic models of the North China Craton, and show that some of the models are viable, and others are not. In this section, we discuss the various proposed tectonic models, summarize the recently published geophysical profiles, then assess which tectonic models have survived the geophysical tests, and which have failed.

One of the most popular models for the tectonic evolution of the North China Craton is the one advocated by G.C. Zhao et al. (Zhao, 2001; Zhao et al., 1998, 1999a,b, 2000, 2001a,b, 2002, 2005, 2007, 2010; Liu et al., in review a). This group has used mostly U–Pb geochronology and metamorphic P–T paths to constrain the temporal and thermal evolution of rocks from different belts, and led to their definition of the North China Craton being divided into two major blocks (Eastern and Western Blocks), separated by an intervening orogen they termed the "Trans-North China Orogen (TNCO; Fig. 2A). Based on their data, these workers suggested that the two blocks formed independently in the Archean, and the western margin of the Eastern Block was an active, Andean-style margin from the late Archean until the two blocks collided