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Destruction of the North China Craton: Lithosphere folding-induced removal of lithospheric mantle?

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ABSTRACT

High heat flow, high surface topography, and widespread volcanism indicate that the lithospheric mantle of typical cratonic character of the North China Craton has been seriously destroyed in its eastern half. However, the mechanism of this process remains open to intense debate. Here lithosphere folding-induced lithospheric mantle removal is proposed as a new mechanism for the destruction of the craton. Four main NNE–SSW-striking lithospheric-scale anticlines and synclines are recognized within North China east of the Helan fold-and-thrust belt. The lithosphere folding occurred possibly during the Late Triassic through Jurassic when the Yangzi Craton collided with the North China Craton. It was accompanied or followed by lithospheric dripping, and could have possibly induced the lithosphere foundering of the North China Craton. The lithosphere folding would have modified the lithosphere morphology, creating significant undulation in the lithospheric base and thus causing variations of the patterns of the small-scale convection. It also could have provoked the formation of new shear zones liable to impregnation of magma, producing linear incisions at the cratonic base and resulting in foundering of lithospheric mantle blocks. Furthermore, it generated thickening of the lithosphere or the lower crust and initiated the destabilization and subsequent removal of the lithospheric mantle.

1. Introduction

Recent studies suggest that the cratonic lithosphere is not stable forever, and can be severely destroyed (decratonized), although it has traditionally been believed that ancient, thick, cold, and refractory cratonic lithosphere has survived at least since the Proterozoic and has not undergone intense magmatism or tectonism since its stabilization (Jordan, 1978; Menzies et al., 1993, 2007; Burg et al., 1994; Conrad and Molnar, 1997; Ebinger et al., 1997; Conrad, 2000; Burov, 2007; Tappe et al., 2007; Gogus and Pysklywec, 2008a, 2008b; see Foley, 2008 for a review). The North China Craton is a counter-example where the lithospheric mantle and even the mafic lower crust have been rather completely removed. For example, there are petrological and geochemical signatures that could be used to explain the past existence of the mantle lithosphere beneath the North China Craton. Xenoliths, dominated by diamond megacrysts, in kimberlite-borne garnet peridotites emplaced in the Ordovician indicate the presence of a mantle of typical cratonic character and composition (180–200 km, 5–6 GPa), and define a "shield" geotherm for Paleozoic times (surface heat flow of 36–40 mW/m^2) (Griffin et al., 1992, 1998, 1999). Diamonds contain solid inclusions dominated by peridotitic minerals and indicate that a keel at 180–200 km was composed of melt-depleted magnesian peridotite or harzburgitic peridotite of low density (see Xu, 2001; Xu et al., 2009 for a review).

On the other hand, surface heat flow data, seismic data and seismic topography models reveal that, today, the eastern part of the North China Craton is characterized by a thinned lithosphere of non-cratonic character, 70–80 km thick, juvenile, hot (>64 mW/m^2), fertile and isotope-depleted (Griffin et al., 1992, 1998, 1999; Menzies et al., 2007 and references therein). Furthermore, an "oceanic" paleo-geotherm (~80 mW/m^2) was defined based on co-existing minerals in Cenozoic basalt-borne spinel–garnet facies xenoliths. Menzies et al. (2007) even proposed that heat flow had peaked in the late Mesozoic (>100 mW/m^2) and has subsided through the Cenozoic (90 mW/m^2) to the present-day (64 mW/m^2).

However, the mechanism of this process remains open to intense debate. It has principally been attributed to (1) removal of thickened North China lower crust and lithospheric mantle due to either the North China–Yangzi collision along the Qinling–Dabie–Sulu belt in its eastern–southern margin (Yang et al., 2008), or the Siberia–North China collision along its northern margin (e.g., Xu et al., 2009); (2) lithospheric extension related

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to subduction of the Pacific plate to its eastern margin (Xu, 2001; Menzies et al., 2007; Xu et al., 2009).

In this paper, previously published geological, geophysical and geochemical data are synthesized and a new hypothesis is proposed for mantle lithosphere removal beneath the eastern side of the North China Craton. It is tentatively proposed that the presence of lithosphere folds in North China due to the North China–Yangzi collision along its eastern margin (Dabie–Tanlu–Sulu belt) during the early Mesozoic, which induced simultaneous/subsequent intense lithospheric dripping of the North China Craton. Given that lithosphere folding is a common geological phenomenon observed in cratons worldwide (e.g., Stephenson and Lambeck, 1985; Goleby et al., 1989; Stephenson et al., 1990; Burov et al., 1993; Nikishin et al., 1993; Cloetingh et al., 1999, 2002; Gerbault et al., 1999; Caporali, 2000), similar processes could have probably played a significant role in modifying continental lithosphere elsewhere.

2. Geological setting

The North China Craton, one of the main continental blocks in China, is bounded to the north by the Yinshan orogen and to the south by the Qilian–Qinling–Dabie–Sulu orogen (Fig. 1a). The Qilian–Qinling–Dabie–Sulu orogen is a product of the collision between the North China and Yangzi cratons during the Triassic or Mid-Paleozoic (Zhang, 2002) and is marked by the largest ultrahigh-pressure (UHP) metamorphic terranes on Earth. The Tanlu fault is the largest fault in the eastern Asian continental margin and it divides the North China Craton from the Yangzi Craton while extending northward into the former. A North–South Gravity Lineament (NSGL, Fig. 1a) possibly represents a major lithospheric boundary within the North China Craton that separates the craton into eastern and western sectors with distinct architectures (Xu, 2001; Yang et al., 2008; Chen et al., 2009; Xu et al., 2009).

The North China Craton is extensively underlain by the Archean basement rocks in China (up to 3.8 Ga; Liu et al., 1992), and it is dominated by widespread Neoarchean tonalite–trondhjemite–granodiorite (TTG) suites as well as minor supracrustal rocks (Yang et al., 2008). The craton was formed in the Paleoproterozoic by the amalgamation of the eastern and western Archean blocks along the Trans-North China suture (Fig. 1b. e.g., Zhao et al., 2001), and was stabilized since at least 1500 Ma (e.g., Menzies et al., 1993; Griffin et al., 1998).

The North China Craton subsequently received marine carbonate sedimentation through the Sinian (uppermost Precambrian) to the Middle Ordovician, records a sedimentary hiatus from the Late Ordovician to the Early Carboniferous, and received continental sandstone and shale sedimentation and local marine limestone from Middle Carboniferous to Triassic times. Widespread late Paleozoic NE-trending calc-alkaline chain volcanism within the eastern flank of the North China Craton around the Tanlu fault zone is marked by calc-alkaline pyroclastic breccias, sedimentary pyroclastic breccias and tuffs, calc-alkaline debrises, crystals, glass shards, and numerous tonsteins in the late Paleozoic clastic sediments. This volcanism indicates an active continental margin flanking the easternmost North China Craton before Triassic times (Zhang, 1997, 2002, 2004).

3. Geological observations of lithosphere folding of North China

3.1. Spatial characteristics

Geological structure in North China is strongly anisotropic, aligned roughly in a NNE–SSW direction (e.g., Ma et al., 2004, Fig. 1b). Accordingly, there is little variation in topographic elevation (Ma et al., 2004) and gravity along strike (e.g., Yuan, 1996), but across strike there are significant variations (Ma et al., 2004; Yuan, 1996), and these are shown in Fig. 2. It is proposed that the NNE–SSW-trending Taihang and Lvliang Mountains and the Zhongyuan–Bohai (northern China) and Ordos basins within North China potentially correspond to whole-lithospheric anticlines and whole-lithospheric synclines, respectively (Figs. 1b and 2). Such whole-lithosphere folding is particularly evident in the well-preserved Ordos basin (syncline), where the geological and deep-seismic observations reveal that no decouple exists between the crust and the mantle lithosphere (e.g., Yuan, 1996; Ma et al., 2004). The wavelengths of whole-lithospheric folding are about 360 km on average, but obviously expand westwards (Figs. 1b and 2). Patterns of lithosphere folds are oriented parallel to the eastern boundary (Tanlu fault zone) of the North China–Yangzi cratons (Fig. 1b). Therefore, two large-scale anticlines and synclines can be easily recognized on a geological map of North China (Fig. 1b). From east to west, they are here named as the Xuhuai–Liaodong and Taihang–Lvliang anticlines and Zhongyuan–Bohai and Ordos synclines, respectively (Figs. 1b and 2).

The two anticlines have extensive Archean and Proterozoic gneiss cores (e.g., Liu et al., 1992; Ma et al., 2004) and are expressed as ridges in the form of lineaments of l–3 km elevation (Ma et al., 2004, Figs. 1b and 2). The two synclines are expressed as linear-shaped or broad depressions (Ma et al., 2004, Figs. 1b and 2). These two synclines are underlain by Paleozoic to Lower Triassic sedimentary cover and filled by Late Mesozoic sediments of up to 1–2 km thick (Zhu et al., 2001; Peng and Wu, 2006; Xu et al., 2009; Zhang et al., 2009). Therefore, these anticlines possibly have ∼4–5 km of structural relief (Fig. 2). It seems clear that the amplitude of folding decreases westward while the spacing increases (Figs. 1b and 2). The observed decrease in wavelength of folding corresponds to the areas of localized contractional deformation situated along the Tanlu fault zone (Figs. 1b and 2).

On the west of the Ordos basin, the intraplate Helan fold-and-thrust belt displays a NNE–SSW strike (e.g., Darby and Ritts, 2002), consistent with that of the lithosphere folds in the North China Craton (Fig. 1b). This tectonic belt seems to mark the western boundary of the lithosphere folds (Figs. 1b and 2).

3.2. Timing

The sedimentary record is a direct expression of lithosphere folding, and thus best defines the timing of lithosphere folding (e.g., Cloetingh et al., 1999). Broad investigations on the sedimentary facies and strata in the North China Craton show that continental siliciclastic deposition since the Carboniferous throughout the North China Craton did not terminate until the end of the Middle Triassic (e.g., Wang, 1985). In particular, during this timespan, the present Taihang–Lvliang mountain belt, that covered the Trans-North China orogenic system (Fig. 1b), was an area that received regular deposition, rather than a topographic high that was exposed to the surface (Wang, 1985; Peng and Wu, 2006, Fig. 3). Sedimentary facies are continuous across these mountains and no marginal facies, characterized by intermontone coarse clastic association, are found on either flank during the Carboniferous (not shown) to the Middle Triassic (Peng and Wu, 2006, Fig. 3). These marginal facies existed only in the western and northeastern margins of the North China Craton (Wang, 1985, Fig. 3).

In contrast, since the beginning of the Late Triassic, sediment deposition gradually withdrew from these mountains as well as the eastern half of the North China Craton and continuous deposition only occurred in the Ordos basin (Wang, 1985, Fig. 3). Even alluvial fans that were generally sourced from these mountains existed in the basins in the eastern half of North China during the Late Triassic to the Cretaceous (Zhu et al., 2001; Peng and Wu, 2006; Zhang