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Research paper

Characteristics of the crystalline basement beneath the Ordos Basin: Constraint from aeromagnetic data

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A B S T R A C T

Aeromagnetic anomaly zonation of the Ordos Basin and adjacent areas was obtained by processing high-precision and large-scale aeromagnetic anomalies with an approach of reduction to the pole upward continuation. Comparative study on aeromagnetic and seismic tomography suggests that aeromagnetic anomalies in this area are influenced by both the magnetic property of the rock and the burial depth of the Precambrian crystalline basement. Basement depth might be the fundamental control factor for aeromagnetic anomalies because the positive and negative anomalies on the reduction to the pole-upward-continuation anomaly maps roughly coincide with the uplifts and depressions of the crystalline basement in the basin. The results, together with the latest understanding of basement faults, SHRIMP U-Pb zircon dating of metamorphic rock and granite, drilling data, detrital zircon ages, and gravity data interpretation, suggest that the Ordos block is not an entirety of Archean.

1. Introduction

Chinese geoscientists have been studying the North China Craton (NCC) for approximate 50 years (Ji et al., 2008). In the last decade, a series of noteworthy achievements has been achieved (Zhao et al., 1998; Zhai et al., 2000; Kusky et al., 2001, 2007; Zhai and Liu, 2001; Zhao et al., 2001a,b; Wilde et al., 2002, 2004, 2005, 2008; Kusky and Li, 2003; Zhai and Liu, 2003; Zhai et al., 2003; Faure et al., 2004, 2007; Guo et al., 2005, 2012; Kröner et al., 2005a,b, 2006; Wilde and Zhao, 2005; Zhai et al., 2005; Zhao et al., 2005; Santosh et al., 2006, 2007a,b, 2008, 2009a,b, 2010, 2012; Kusky and Santosh, 2009; Santosh, 2010; Santosh and Kusky, 2010; Kusky, 2011a,b; Peng et al., 2011, 2012; Wan et al., 2011, 2012; Zhai and Santosh, 2011; Lü et al., 2012; Du et al., 2013; Li et al., 2013a,b; Ren et al., 2013; Yang et al., 2013; Zhao and Zhai, 2013; Zheng et al., 2013). Among them, the research on the NCC destruction has been a particular point of emphasis (Xu, 2001; Zhang et al., 2002, 2012a,b; Yang et al., 2008; Xu et al., 2009; Zhu and Zheng, 2009; Wang et al., 2010; Lan et al., 2011; Lin et al., 2011; Pei et al., 2011; Tian and Zhao, 2011; Xiong et al., 2011; Zhang et al., 2011; Zhu et al., 2011; Huang et al., 2012; Li et al., 2012a,b,c; Wang et al., 2012; Zhang, 2012a,b; Zhang et al., 2012a,b,c; Zheng et al., 2012; Zhou et al., 2012a,b; Zhu et al., 2012a,b; Li, 2013; Ling et al., 2013; Shen et al., 2013; Xia et al., 2013)—it is regarded as the best example of craton destruction by the international academic community (Carlson et al., 2005). Widespread agreement has been achieved that large-scale lithospheric mantle thinning and transformation beneath the eastern NCC occurred mainly in the Mesozoic. Nevertheless, compared with the eastern NCC, which has thinner lithospheric mantle (only 60–100 km), about 200 km-thick craton-style lithosphere remains beneath the Ordos Basin, except for the Yinchuan-Hetao and Fen-Wei thin-lithosphere rift-depressions, which are less than 100 km thick, that formed in the Cenozoic (Chen et al., 2006, 2008, 2009a,b; Chen, 2009; Zhu et al., 2011, 2012b; Cheng et al., 2013). This means that the Ordos block did not experience lithospheric thinning like what had happened in the Eastern Block of the NCC. Therefore, lithospheric features of the Ordos block, especially characteristics of its deep basement, hold the attention of those geologists who are engaged in the study of the NCC. However, so far, little is known about its basement features. Much of the current knowledge was hypothetical, based on indirect geophysical data and outcrops around the Ordos Basin (Ma et al., 1979; Zhang, 1982, 1989; Guan et al., 1987; Hu et al., 1990; Zhang et al., 1991; Wang and Zhang,

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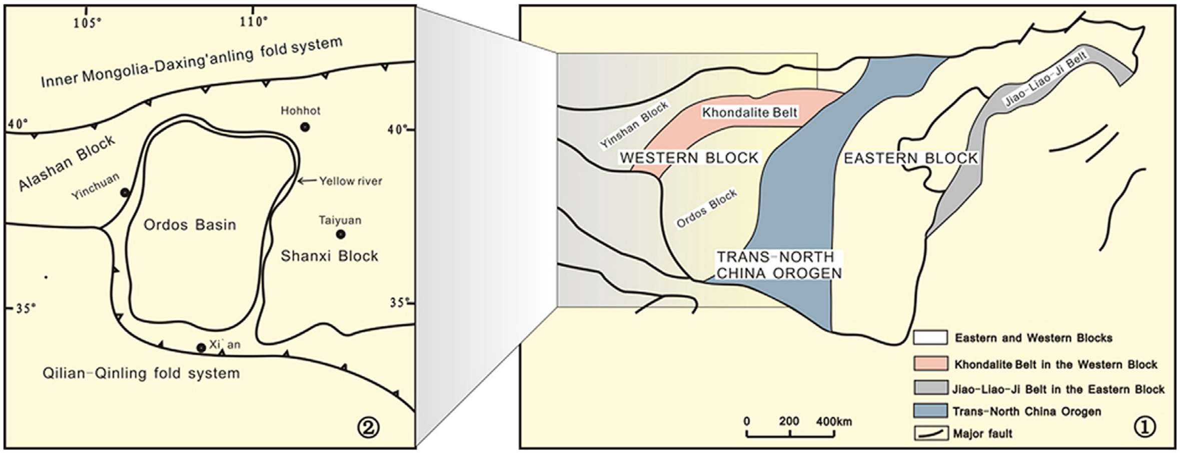

Figure 1. Regional tectonic position of the Ordos Basin (① after Zhao et al., 2005; ② after Xue et al., 2011).

1992; Bai et al., 1996; Jia et al., 1997; Deng et al., 1999, 2005; Ding, 2000; Jiang et al., 2000; Bai et al., 2007; Wang et al., 2007; Li and Gao, 2010).

Magnetic variations can reveal the distributions of various rock types, ages, and fold structures of mountain belts. Most of the significant tectonic phenomena in the Ordos Basin can be clearly demonstrated in regional aeromagnetic anomaly maps (Wu et al., 2003); similar basin basement features elsewhere also have been studied by aeromagnetic anomalies (Johnson and Swain, 1995; Ram et al., 2007; Bahadur et al., 2008). The aeromagnetic anomalies range from −514 to +904 nT and reveal different zones with distinct anomaly amplitudes. On the basis of aeromagnetic anomalies, the Ordos Basin can be divided into several parts. Along with recent progress made by regional geological surveys, drilling, isotope chronology, and seismic tomographic imaging information, we make an integrated interpretation to direct future research on the Ordos Basin basement.

2. Geological background and rock magnetism characteristics

The Ordos Basin, a major source of hydrocarbons, is located in the western NCC (Fig. 1). It occupies an area of approximately 320,000 km^2 and is bordered by 35° and 40°30′ N and 106°20′ and 110°30′ E (ECPGC, 1987). The Ordos Basin is a cratonic basin with stable subsidence and multicycle sedimentation (Yang, 2002). It is characterized by simple structures, gentle changes in the crust thickness, and geologic units inclined to the west within the basin (Yang et al., 2005). It also exhibits features of holistic rigidity and internal heterogeneity (Jia and Zhang, 2005). The Ordos Basin developed rectangular fault blocks in the Paleozoic era and was cut by an adjacent, faulted depression system in the Cenozoic era (Zhang, 1989). Consequently, its tectonic framework appears as a stable block surrounded by active tectonic belts. It is bounded to the north by the Hercynian orogenic belt in the Inner Mongolia–Daxing'anling area (Xue et al., 2011), and to the south by the Indosinian orogenic belt in the Qilian–Qinling area (Xue et al., 2011). It is separated from the Shanxi block in the east and the Alashan block in the west (Fig. 1).

The crystalline basement beneath the Ordos Basin is covered by Neoarchean, Paleoproterozoic, Meso-Neoproterozoic, Paleozoic, and Meso-Cenozoic deposits, that average 4–5 km thick (Yang, 2002; Yang et al., 2005). Basement metamorphic rocks outcrop sporadically around the basin (Zhai and Liu, 2003; Xia et al., 2006a,b, 2008), and the framework of "three uplifts and two depressions" is distributed from north to south (Yang, 2002). In general, magnetism of metamorphic rocks and igneous rocks is higher, but is lower for the sedimentary cover (Wang and Zhang, 1992; Li and Gao, 2010). Thus, the distribution of crystalline basement rocks can be assessed via aeromagnetic anomalies. Positive magnetic anomalies in the Ordos Basin and adjacent areas are mainly induced by Archean–Paleoproterozoic metamorphic gneiss, leptynite, basic volcanic rocks and syn-tectonic granite (Table 1).

3. Aeromagnetic data and methods

The aeromagnetic data presented in the course of this study were collected by the China Aero Geophysical Survey and Remote Sensing Center for Land and Resources (AGRS) over the Ordos Basin and its adjacent areas from 34–41°N and 106–110°E, at a scale of 1:20,000. The aeromagnetic data on the AGRS CD comprise 88,558 sets of line data. Line-data files are in the Geosoft database format (XYZ file). Each line data set consists of individual magnetometer readings with pertinent locational information, as well as magnetic anomaly values along each line.

Processing aeromagnetic data involves the sequential processes of editing, correcting for diurnal effects, removing the Earth's background magnetic field, leveling of all data to a common base, and, finally, applying a gridding routine. To improve the interpretation of the aeromagnetic data, two magnetic-data-enhancement procedures were employed in the study area: frequency-domain reduction to the pole and upward continuation.

Reduction to the pole is a filter used in low-magnetic latitudes to change an anomaly to its equivalent at the north magnetic pole. This process removes the skewness of the anomalies to make the

Table 1
Magnetic magnetism of rocks in Ordos Basin (after Li and Gao, 2010).

Geological age	Rocks	Magnetic magnetism ($\times 10^{-5}$ SI)
Archean–lower Proterozoic	Gneiss and leptynite, basic volcanic rocks, granite	1800–5000
	Migmatite and marble	20
Middle–upper Proterozoic	Low grade metamorphic rock	1–9
Paleozoic	Carbonate rock and continental clastic rock	<20
Mesozoic	Coarse clastic rocks such as conglomerates and coarse sandstones	1–9
	Mudstone, siltstone	10–30
Cenozoic	Aeolian sands	50