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Distribution of the crustal magnetic anomaly and geological structure in Xinjiang, China

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ABSTRACT

Based on the high-order crustal magnetic field model NGDC-720-V3, we investigate the distribution of crustal magnetic anomaly, the decay characteristics of the anomaly, and the relationship between the magnetic anomaly and geological structure in Xinjiang, China. Topography of the magnetic layer basement is studied through Curie isothermal surface using the power spectrum method. It is found that south Tarim Basin, Junggar Basin, and Turpan–Hami Basin have strong positive magnetic anomaly, whereas west Kunlun Mountain, Altun Mountain, Tianshan Mountain, and Altai Mountain have weak or negative anomaly. The magnetic anomaly well reflects the regional tectonic structure, i.e., three alternating mountains intervened by two basins. The magnetic anomaly on the ground surface in Tarim Basin is well corresponding to the mafic dykes. The decay of the magnetic anomaly with altitude indicates that Xinjiang is a large massif composed of several magnetic blocks with different sizes in different directions. The Curie surface presents a feature of being shallow under mountains whereas being deep under basins, roughly having an anti-mirror correspondence with the Moho depth.

1. Introduction

Crustal magnetic field arises from magnetic rocks in the crust and upper mantle. Because rocks change in magnetism with tectonic evolution, they contain information on crustal magnetic material distribution and record of tectonic evolution (Xu, 2009; Hemant and Maus, 2005). Xinjiang is located on the north side of Tibetan Plateau, lying among several paleocontinents such as Indian Platform, Arabian–Nubian Shield, Russian Platform, and Siberian Platform. Under their mutual actions, tectonics in this region is relatively active and mineral resources are rich.

Study of the spatial distribution of crustal magnetic field in Xinjiang and analysis of the relationship between the magnetic anomaly and the geological structure can provide insight on the origin of the crustal magnetic anomaly. Since 1950s, magnetic anomaly and geological structure in Xinjiang have been investigated by aeromagnetic survey and satellite magnetic survey. Deng et al. (1992) utilized the data from aeromagnetic survey to make a preliminary geological interpretation of magnetic anomaly in Xinjiang. Zhang and Zhang (2007) investigated the geological structure and tectonic evolution of Altun Mountain fault zone based on aeromagnetic survey data. Achache et al. (1987), Arkani et al. (1988), Zhang (2002), and Kang et al. (2010) studied satellite magnetic anomaly over Xinjiang and concluded that positive magnetic anomaly covers most of Xinjiang, with the focus located in South Tarim Basin. However, there are limitations in the study of crustal magnetic anomaly using aeromagnetic survey or satellite data alone (Zhou et al., 2002; Xiong, 2009). Aeromagnetic anomaly cannot well reflect the deep magnetic source; while satellite magnetic anomaly just reflects the distribution feature of macro-scale basement anomaly. In June of 2009, the National Geophysical Data Center (NGDC) of the United States established a geomagnetic field model NGDC-720-V3 (see http://geomag.org/models/index.html) by combining data from satellite, ground, oceanic, and aeromagnetic surveys. In that model, the order of spherical harmonic functions is up to 740 and the resolvable spatial wavelength is as fine as 55 km. Thus the model enables us to study the crustal magnetic anomaly in Xinjiang accurately (Kang et al., 2011).

Curie isothermal surface is a thermal boundary for crustal rock minerals to transform from ferromagnetism to paramagnetism. It is the lower boundary of magnetic layer. Researches on Curie isothermal surface can help understand deep structure of crust and have important application in assessment/exploration of hydrocarbon resource. Curie isothermal surface can be inverted for from crustal magnetic anomaly. For instance, the distribution of the Curie isothermal surface in Tarim Basin was inverted for Lu and Yang (1996), Li and Xiao (1999).

In this paper, we shall according to the NGDC-720-V3 model, calculate the spatial distribution of crustal magnetic anomaly in Xinjiang, study how the magnetic anomaly decays with altitude, invert for the Curie isothermal surface using the power spectrum

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analysis, and finally discuss the relationship between the magnetic anomaly and geological structure in this region.

2. Geotectonic background

The current crustal structure in Xinjiang was finalized in Cenozoic Era. Due to the collision between Indian-Australian Plate and Euroasian Plate, the major tectonics of Xinjiang is featured with basins and mountains. There are three great mountains in Xinjiang, i.e., Altai Mountain in the north, Tianshan Mountain in the center, and West Kunlun Mountain plus Altun Mountain in the south. Between these three mountains lie Junggar Basin and Tarim Basin. The landform framework is three alternating mountains intervened by two basins (Fig. 1). Tianshan Mountain, Kunlun Mountain, and Altun Mountain are orogenic belts that formed in Cenozoic Era (Zhu et al., 2011), which indicates intense tectonic activity (Li and Xiao, 1999; Li et al., 2006).

Now we briefly introduce the geotectonic history of Tarim Basin and Junggar Basin. Recent paleogeographic models (Li et al., 1996; Li and Powell, 2001; Metcalfe, 2009; Turner, 2010) have inferred that the Tarim Block is a craton and was originally connected to the Kimberley region of northwest Australia, forming part of East Gondwana. Correlations of the stratigraphy in the two areas revealed that both have a crystalline basement overlain by remarkably similar Neoproterozoic strata (Brookfield, 1994; Corkeron et al., 1996; Li et al., 1996; Grey and Corkeron, 1998) and occupied similar paleo latitudes during the Middle to Late Neoproterozoic (Chen et al., 2004; Huang et al., 2005; Zhan et al., 2007).

Later on, the cratonic, Precambrian basement of Tarim Basin was overlain by a thick (3–16 km) sedimentary succession (Bally et al., 1986) which records the progressive tectonic and paleogeographic evolution of the basin and the adjacent region since the Late Neoproterozoic (Carroll et al., 1995; Carroll et al., 2001). In south and central Tarim Basin is a large-scale marine-continental sedimentary rock from Paleozoic to Cenozoic (Xu et al., 2005), while in north Tarim Basin, the Precambrian metamorphosed basement widely crops out (Xu et al., 2013). Permian molasses and continental volcanic rocks (including A-type rapakivi granites) are exposed at the northern margin of Tarim Basin (Yang et al., 2007b; Pirajno et al., 2008; Tian et al., 2010). These volcanic rocks are associated with a mantle plume beneath the Tarim Block (Zhang et al., 2010a, b).

Junggar Basin is located in northern Xinjiang, separated from Tarim Basin by Tianshan Mountain. Geologically, this basin is not a craton (Zhao and Cawood, 2012), but a junction between Siberia Plate and Kazakhstan Plate, and is part of the Central Asian Orogenic Belt (Windley et al., 2007; Kröner et al., 2007; Pirajno et al., 2009; Rojas-Agramonte et al., 2011). Unlike Tarim Block, the ancient Junggar Block had formed by the superposition of island arcs in the Ordovician, the Silurian, the Devonian, and the Carboniferous (Li and Xiao, 1999). Thus, a lot of calc-alkali igneous rock and its clasolite are present in Junggar Block. A variety of granitic rocks, including M-, A- and I-types, have been found around Junggar Basin (Xiao et al., 1992). Previous research suggested that most of the granitic rocks intruded between 320 and 350 Ma (Zhou, 1989) with a few at 400 Ma (Hu et al., 1997).

In late Carboniferous, the Junggar block was transformed into a residual sea basin with the closing of Kangur Basin (Li and Xiao, 1999). Thus Junggar Basin has sediments of marine-terrigenous facies mixed with volcanic rock (associated with island arcs). In the subsurface, the basin is filled with thick continental sedimentary rocks not older than early Permian (XBGMR, 1993) and surrounded by a number of Paleozoic ophiolite belts. The surrounding of the thick, young continental sediments by the Paleozoic ophiolite belts (a section of oceanic crust) strongly indicates that Junggar Basin was a sea basin which later on was uplifted above sea level to become part of the continent).

3. Calculation of the crustal magnetic anomaly

In the spherical harmonic series of geomagnetic field, terms with harmonic degrees $n \geqslant 16$ serve as the crustal magnetic field (Maus et al., 2007; Purucker, 2007; Hemant et al., 2007). The spherical harmonic series of vertical component ΔZ of the crustal magnetic anomaly can be expressed as follows:

$$\Delta Z = -\sum_{n=16}^{N}\sum_{m=0}^{n}(n+1)\left(\frac{a}{r}\right)^{n+2}(g_n^m \cos m\lambda + h_n^m \sin m\lambda)P_n^m(\cos\theta) \quad (1)$$

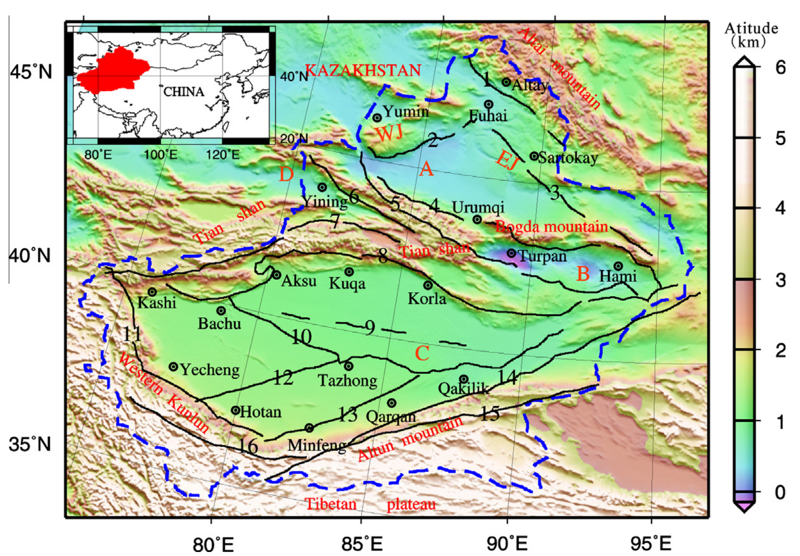

Fig. 1. Topography and tectonics of Xinjiang and its neighboring area. Topographical data courtesy from http://www1.gsi.go.jp/geowww/globalmap-gsi/gtopo30.html. *Note*: The study region (red in the small map) is encircled by blue line. Location of geological structure from Xiao et al. (2010), Liu (2006), Song (2005), Zhang (1982). A—Junggar basin; B—Turpan–Hami Basin; C—Tarim Basin; D—Yili basin; WJ—West Junggar; EJ—East Junggar. 1—Irtysh Fault; 2—Darbut Fault; 3—Karamaili Fault; 4—North Tianshan Mountains Piedmont Fault; 5—North Margin of Central Tianshan Mountains Fault; 6—Ebinur Lake Fault; 7—South Margin of Central Tianshan Mountains Fault; 8—Korla Fault; 9—Arakan Fault; 10—Tumxuk Deep Fault; 11—Kegang-Tacang Fault; 12—Karakax Fault; 13—Great North Minfeng Fault; 14—Luobuzhuang Fault; 15—Altun Fault; 16—Kangxiwar Fault.