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Study on crustal magnetic anomalies and Curie surface in Southeast Tibet

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ABSTRACT

In this paper, the Potsdam model POMME-6.2 is used to investigate the distributions of crustal magnetic anomalies and Curie surface in Southeast Tibet. The Curie surface is compared with the regional heat flow, Bouguer anomaly, Moho depth, and seismicity. The results show that the magnetic anomalies and Curie surface are both consistent with the geological structure. Sichuan Basin exhibits a high positive anomaly, while orogenic belts such as the Longmenshan, northwestern Sichuan, and western Yunnan, exhibit weak positive or negative anomalies. The distribution of magnetic anomaly confirms that escape flow from east Tibet branches into northeastward part and southward part on west Sichuan Basin, due to resistance by the rigid basin. The depth of Curie surface ranges from 20 to 34 km. The Curie surface beneath the Longmenshan, Xiaojiang and Lijiang–Xiaojinhe faults is shallow, with the uplift strike consistent with the faults. The Curie surface beneath Sichuan Basin and the central Bayan Har massif is deep, with sheet-like depressions. Strong earthquakes primarily occurred in the areas with the uplift of Curie surface. The heat flow values near Tengchong, Lijiang, Dali and Kunming are high and the Curie surface there is shallow.

1. Introduction

Curie isothermal surface (also called Curie surface) is a thermal boundary for crustal rock minerals to transform from ferromagnetism to paramagnetism. It is the lower boundary of the magnetic layer in the crust. The surface indicates the distribution of the thermal fields underground, providing a clear marker for the thermodynamic effect in crust and mantle (Xu, 2009). The depth of Curie surface varies from region to region, mainly depending on the regional geology, the geothermal flow, and the mineral content in rock (İbrahim et al., 2005; Manea and Manea, 2011). Research on Curie surface can provide valuable insight in assessment of geothermal energy, calculation of thermal conductivity, as well as reconstruction of tectonic evolution (Hu et al., 2006; Rajaram et al., 2009).

There are two main methods for the detection of Curie surface, i.e., geothermal method and magnetic method (Eppelbaum and Pilchin, 2006; Hamed and Nabi, 2012). The geothermal method is based on geothermal data on heat flow, geothermal gradient, and heat conduction. However, as it is unable to directly measure the geothermal parameters at large depth, this method has its limitation (Tanaka et al., 1999). According to the definition of Curie surface, the most commonly used method to estimate the Curie point depth is through the magnetic data (Li et al., 2010). For different research targets, researchers employ different techniques to determine the Curie surface depth using magnetic anomaly data (Bhattacharyya, 1966; Spector and Grant, 1970; Bhattacharyya and Leu, 1975). Among these methods, the magnetic anomaly spectral analysis based on the theory proposed by Bhattacharyya (1966) and the improvement of statistics theory by Spector and Grant (1970) as well as Bhattacharyya and Leu (1975) is an effective method to detect the top and bottom depths of a magnetic body, thus being widely applied. Many scholars used this method to investigate Curie surface in different regions (Shuey et al., 1977; Mayhew, 1985; Blakeley, 1988; Tanaka et al., 1999; Ravat et al., 2007; Arnaiz-Rodríguez and Orihuela, 2013).

Chinese scholars studied the Curie surface in mainland China and the coastal regions by using aeromagnetic data. According to the magnetic anomaly power spectral method, Hu et al. (2006) inverted for the Curie surface in Northeast China, and their result showed that the variation trend of the Curie surface is significantly correlated with the variation of the lithosphere–asthenosphere boundary. Li et al. (2009, 2010) estimated the Curie surface in several regions of China, including South China Sea, East China Sea, and Yellow Sea, and delineated oceanic and terrestrial tectonic

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units based on the inversion results. Gao et al. (2013) calculated the Curie surface in Xinjiang, China and concluded that the Curie surface and Moho surface depths exhibit an anti-mirror correspondence relationship in that region. The Curie surface in Southeast Tibet was also analyzed. For instance, Zhang et al. (1996) estimated the Curie surface depth in Sichuan Basin and its marginal seismic areas by using the three-dimensional magnetic layer inversion method. They thought that the variation of the Curie surface has a direct relationship with the geological structure, and then discussed the relationship between the Curie surface and the seismicity distribution. Shen et al. (1986) concluded the Curie surface depth ranged from 20 km to 30 km in Xikang–Yunnan continental paleo-rift zone by using the matrix spectral method in frequency domain, together with the linear inversion and integral iterative method in spatial domain. Although the near-surface aeromagnetic survey resolution is high, such survey involves different measuring times with different measuring methods (Zhang, 2009). For this reason, the Curie surface calculated with these aeromagnetic data may vary significantly in the same region and do not correspond to each other.

The Curie surface reflects the lower interface of magnetic bodies, and estimation of its depth requires long-wavelength magnetic anomaly data (Pilkington et al., 2006). Since magnetic survey satellites run at a high altitude above 300 km, at which the local short-wavelength magnetic anomalies will completely attenuate, the satellite-obtained magnetic anomalies mainly reflect the basement anomaly feature on a large scale (Hemant and Maus, 2005). Rajaram et al. (2009) calculated the Curie surface in Indian subcontinent by independently using satellite data and aeromagnetic data. The Curie surface variation trends obtained from the two methods are consistent. In this paper, we first introduce the geological structural background of Southeast Tibet in Section 2. In Section 3, we calculate and analyze the spatial distribution characteristic of the total crustal magnetic field intensity ΔF in Southeast Tibet based on the Potsdam magnetic model POMME-6.2 (Maus et al., 2006, 2010) that was established according to the data from satellite, ground, airborne and seaborne magnetic survey. The relationship between the magnetic anomalies and the geological structure is discussed. We estimate the Curie surface in Southeast Tibet in Section 4. Finally, in Section 5, we compare the Curie surface, the geothermal flow, gravity anomaly, Moho depth and seismicity.

2. Geotectonic background

Southeast Tibet is in a domain involved in the convergence of and interaction between the Eurasian and Indian plates (Hu et al., 2013; Huang et al., 1980). This region is also the transition zone connecting Tibet Plateau with Yangtze Craton and Indochina Block (Fig. 1). Our study area includes Yunnan, Sichuan, parts of Guizhou, Guangxi and Tibet of China, in addition to North Vietnam and Northeast Myanmar. In this region, the crustal thickness varies from 35 km in the southwest to more than 60 km in the northwest, with a variation magnitude of over 25 km (Kan et al., 1986).

Due to intense collision between the Indian and Eurasian plates, faults were developed in Southeast Tibet (Kan et al., 1997; Han and Jiang, 2004). Relatively large fault zones include: the Longmenshan fault zone, the Xianshuihe fault zone, the Sanjiang fault zone, the Ailaoshan–Red River fault zone, the Jinpingshan–Yulongxueshan fault zone, the Zemuhe–Xiaojiang fault zone, the Kangding–Yiliang–Shuicheng fault zone, and the Mile–Shizong–Shuicheng fault zone. These fault zones divide Southeast Tibet into multiple blocks (Shen et al., 2003) such as the Bayan Har block, the Sichuan Basin (the Yangtze block), the Sichuan–Yunnan rhombic block (the northwestern Sichuan massif and the central Yunnan block), the eastern Yunnan block, the Tengchong–Baoshan (the western Yunnan) block, and the Indochina block (Fig. 1). These blocks include relatively stable ancient blocks (e,g., Sichuan Basin), as well as Cenozoic orogenic belts such as the Longmenshan, northwestern Sichuan, and western Yunnan orogenic belts.

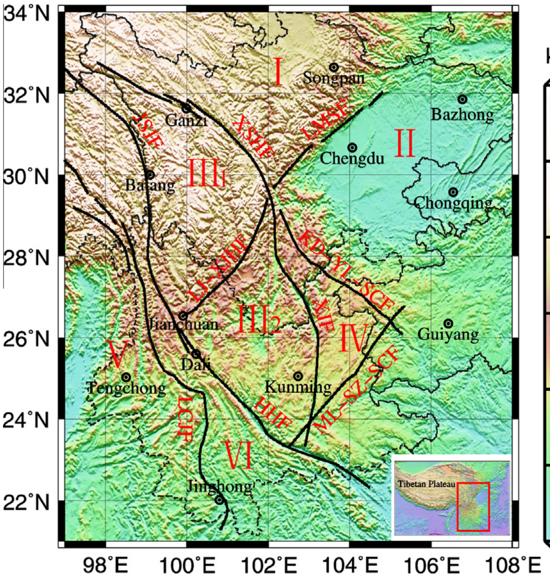

Fig. 1. Topography and tectonics of Southeast Tibet. The red square of the small bottom right map represents the study region. Modified from Chen et al., 2013. I—Bayan Har block; II—Sichuan Basin; III_1—Northwest Sichuan Block; III_2—Central Yunnan Block; IV—Eastern Yunnan Block; V—Western Yunnan Block; VI—Indosinian Block; JSJF—Jinshajiang Fault; XSHF—Xianshuihe Fault; LMSF—Longmenshan Fault; LJ–XJHF—Lijiang–Xiaojinhe Fault; LCJF—Lancangjiang Fault; HHF—Honghe Fault; XJF—Xiaojiang Fault; KD–YL–SCF—Kangding–Yiliang–Shuicheng Fault; ML–SZ–SCF—Mile–Shizong–Shuicheng Fault.

Southeast Tibet is located in the southern section of China north–south seismic zone where strong earthquakes occur frequently. It is one of the regions with the most frequent seismic activity in mainland China (Han and Jiang, 2004; Zhang, 2013). The seismic activities are characterized by high frequency, large intensity, and severe disaster. Since 1970, there 9 strong earthquakes over Ms 7 occurred. The earthquakes are primarily distributed along the fault zones on the block boundaries. In particular, the Sichuan–Yunnan rhombic block localizes the majority of earthquakes. The focal depths of most of the earthquakes range from 5 km to 25 km, located in the upper and middle crust.

The geothermal flow in the study region has relatively large horizontal variations with high and low values in the east and west, respectively (Zhou et al., 1997; Xu et al., 2011). The area to the west of Lancang River, as a part of Himalayan high geothermal zone, belongs to continental subduction zone of the Burma–Andaman segment of the Indian plate, having high geothermal values. The Tengchong volcanic area, where neotectonic movement is active, is one of the areas with recent volcanic activities in China. Its maximum geothermal flow is 118 mW/m^2, nearly 2 times the global mean value (61.6 mW/m^2) (Chapman and Rybach, 1985), and the mean geothermal flow in this massif is 91 mW/m^2 (the number of measuring points is $n = 8$), which is still close to 1.5 times the global average. The Yanyuan–Lijang continental margin depression has a geothermal flow value close to that in the Tengchong massif. The geothermal flow value measured in Xiaguan located on the Red River fault is 66–103.4 mW/m^2, and that located on the Longpan–Jianchuan fault is 97.1–98.5 $mW/\ m^2$. The geothermal heat flow values in the eastern Yunnan area and Sichuan Basin are relatively low. Sichuan Basin has geothermal flow values at 35.4–68.8 mW/m^2 with a mean value of 53.2 mW/m^2, having the medium and low geothermal flow characteristic of a typical intracratonic basin.