Magnetic constraints on the spatial distribution of seismic activity

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Abstract The lithospheric magnetic field (LMF) in China and its surrounding are calculated using the spherical harmonic coefficients given by the NGDC-720 model. The LMF comes from the magnetization of minerals in the crust and in the uppermost mantle. It may, therefore, provide unique insight into lithospheric tectonic processes and mechanisms. Here, we study the geomagnetic manifestation of active tectonic blocks, and find a close correlation between the LMF and seismicity. Many large faults are found to closely overlap with magnetic anomalies, or are distributed along the boundaries of magnetic anomalies. Earthquakes in these fault regions have occurred on the boundaries of magnetic anomalies, or in the transition zones between positive and negative anomalies. We analyze the components of the LMF, and the LMFs at different altitudes, finding that the vertical component, B_z at 200 km, is the most related to seismic activity. Relevant physical mechanisms are also discussed. We propose that the stress or viscosity differences caused by temperature variations, which manifest in the LMF, may be the predominant reason for the correlation between the LMF and seismic activity along large faults.

Keywords NGDC-720 · Lithospheric magnetic field · China · Active tectonic block · Seismic activity

1 Introduction

The lithospheric magnetic field (LMF) is generated by the magnetization of lithospheric minerals (mainly magnetite and maghemite) in an ambient field, which is usually the earth's core magnetic field. The LMF is influenced by the spatial and temporal variations of the ambient field. However, it can be sustained without an existing ambient field, as is the case on Mars (Acuña et al. 1999). Previously, it was thought that minerals in the mantle do not contribute to the LMF because all of the iron resides almost exclusively in non-magnetic silicates below the Mohorovičić discontinuity (Moho) (Thébault et al. 2010). The iron in crustal magnetic minerals is mostly contained in magnetic oxides, so the LMF was (and in some cases, still is) referred to as the crustal field. However, subducting oceanic slabs may transform nonmagnetic peridotite into highly magnetic serpentinite (Blakely et al. 2005). During this process, it is possible for the descending slab to cool the mantle below the Curie temperature (the critical temperature for the transformation of ferromagnetism to paramagnetism), a process that is occurring in the Cascadia and Alaskan subduction zones (Blakely et al. 2005). Taking this into consideration, the LMF may be a more proper term than the crustal field.

The LMF cannot be measured directly on the Earth because it is overprinted by the Earth's main magnetic field (or core field), which comprises 95 % of the total surface geomagnetic field. The LMF makes up only about 0.1 %–4 % of the total field, depending on location and altitude (Xu 2009). The LMF is manifested as a perturbation to the dominant main field and is, thus, also referred to as a magnetic anomaly. The Earth's magnetic field has been measured for over 400 years, whereas a global LMF map was only achieved about 30 years ago in the era of MAGSAT, a magnetic satellite launched by the USA. After 1999, three

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other important magnetic satellites (Orsted, SAC-C, and CHAMP) were launched. The high resolution and precision data obtained from these satellites made it possible to build more accurate LMF models, including CM4, MF6, and NGDC-720, among others (Xu et al. 2008). Global and regional LMF models are very useful for the study of plate tectonics and lithospheric dynamics.

Unlike the North American craton, China and its surrounding are composed of many separate tectonic units, including: cratons, orogens, plateaus, and basins. These topographic variations are shown in Fig. 1 (topography data were downloaded from the ETOPO1 global relief model site: <http://www.ngdc.noaa.gov/mgg/global/global.html>, see Amante and Eakins B 2009). Previous studies have shown that plate interiors in this area move as active, cohesive blocks (Deng et al. 2002), shown in Fig. 1 (block data are from Zhang et al. 2003). Different tectonic units may exhibit diverse LMF characteristics, making China and the surrounding area one of the best regions to study the correlation between tectonics and the LMF.

The satellite LMF has been compared to the geology of China as early as the MAGSAT era. Magnetic anomaly maps were built and examined in relation to the geology and heat flux by An et al. (1992), Xu (1997), Xu et al. (2000), and Alsdorf and Nelson (1999). After the launch of CHAMP, Wang et al. (2008) discussed the distribution of some new

global LMF models. Kang et al. (2010) calculated and compared the components and the vertical gradient of the magnetic anomaly with lithospheric tectonics. Kang et al. (2012) used the NGDC-720 model to analyze the crustal magnetic anomalies and regional tectonics of the Tibetan Plateau according to the power spectrum. Some basic correlations have so far been addressed, but no studies have focused on the correlation between satellite LMF models and China's active tectonic blocks. Furthermore, because earthquakes are closely related to tectonics, seismic activity may also be linked to the LMF. Although several pioneering studies have addressed this subject (Li et al. 1992; An 2004; Wei and Yu 2012), the correlation between earthquake activity and the LMF is still in need of further study. This paper aims to clarify this correlation and to discuss the potential physical mechanisms that may influence the correlation.

2 LMF model and seismic record selection

2.1 LMF model

The global magnetic field model is generally represented by Gaussian spherical harmonic expansion. The magnetic potential U is written as:

Fig. 1 Topography of the research area and the active tectonic blocks. Level I and II block boundaries are shown as *red solid lines* and *black dashed lines*, respectively

$$U^i(r, \theta, \phi) = a \sum_{n=1}^N \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+1} (g_n^m \cos m\phi + h_n^m \sin m\phi) P_n^m(\cos \theta) \quad (1)$$

where i denotes the internal source, a is the Earth reference radius ($a=6371\text{km}$), r , θ , ϕ are the radius, geocentric co-latitude and longitude, respectively, g_n^m and h_n^m are Gaussian coefficients, P_n^m is the Schmidt semi-normalized associated Legendre function of integer degree n and order m , and N is the max degree. Generally, n is taken from 1 to 13 to denote the main field, and from 16 to N to denote the LMF. The horizontal spatial wavelength λ (in km) is associated with each degree by (Backus et al. 1996):

$$\lambda = \frac{2\pi a}{\sqrt{n(n+1)}} \approx \frac{2\pi a}{n} \quad (2)$$

Among the various LMF models, the NGDC-720 static model (Maus 2010) is selected because of its high resolution. The NGDC-700 is a combined model including data from satellites, and in situ marine and airborne surveys. The model has a maximum degree of 720, thus, according to Formula (2), the horizontal wavelength at the surface of the model is 56–2,500 km. The low degree coefficients ($16 \leq n \leq 120$) are the same as in model MF6 (Maus et al. 2008), which was built with low orbital data from the CHAMP satellite between 2004 and 2007. The high degree coefficients ($120 < n \leq 720$) are calculated by a global LMF grid, EMAG2, which has a resolution of $2' \times 2'$ (Maus et al. 2009).

All LMF components, including inclination and declination, can be calculated from Formula (1), but here we calculate only the three components B_x (northward), B_y (eastward), B_z (downward) and the intensity, B :

$$\begin{cases} B_x = \sum_{n=16}^{720} \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+2} (g_n^m \cos m\phi + h_n^m \sin m\phi) \frac{\partial P_n^m(\cos \theta)}{\partial \theta} \\ B_y = \sum_{n=16}^{720} \sum_{m=0}^n \left(\frac{a}{r}\right)^{n+2} (g_n^m \sin m\phi - h_n^m \cos m\phi) \frac{m P_n^m(\cos \theta)}{\sin \theta} \\ B_z = - \sum_{n=16}^{720} \sum_{m=0}^n (n+1) \left(\frac{a}{r}\right)^{n+2} (g_n^m \cos m\phi + h_n^m \sin m\phi) P_n^m(\cos \theta) \\ B = \sqrt{B_x^2 + B_y^2 + B_z^2} \end{cases} \quad (3)$$

Another definition of the intensity B could be found in Kang's paper (Kang et al. 2010). Model coefficients were downloaded from <http://geomag.org/models/ngdc720.html>.

The aeromagnetic compilations of China and surroundings were provided by GETECH (<http://www.getech.com/>) and CCOP (<http://www.ccop.or.th/>). To get more information about the short wavelength magnetic data, one could visit the two websites.

2.2 Active tectonic and seismic records

Many studies have addressed China's active tectonic blocks (Deng et al. 2002; Wang et al. 2003; Zhang et al. 2003) but we implement a generally accepted model from the work of Zhang et al. (2003), which is based on active fault research and observations of GPS crustal movement. "Active" means that tectonic boundaries/faults formed in the late Cenozoic or the late Quaternary (0.1–0.12 Ma), and we have examined both 6 level I (large) and 22 level II (relative small) active blocks. The level I blocks, also referred to as the fault block zones, include the West Region, Tibet, Burma, South China, North China, and Northeast Asia. They are shown in Fig. 1, together with the level II blocks.

Earthquake list was obtained from the China Earthquake Networks Center (CENC, <http://www.csnrmc.ac.cn/newweb/data.html>). The long-wavelength section of the NGDC-720 model is composed of only 4 years of CHAMP data, whereas the short wavelength section is composed of over 20 years of aeromagnetic and marine observations (one may check <http://geomag.org/models/EMAG2/acknowledgments.html> for more details). In 2012, Wei and Yu studied the correlation between the earthquakes with magnitude ≥ 5.0 (2004–2007) and the LMF given by the MF6 model. But 4-year time might be too short to contain enough large earthquakes (especially in Eastern

China). On the other hand, the structure of the lithospheric changes on geological time scales, but the Earth's main magnetic field typically changes on a scale of decades

(Kuang and Chao 2001; Olsen et al. 2007). Therefore, we mainly select earthquakes that have occurred in the most recent decade (2003–2012). To check long-term trends, we also make use of expanded data from 1970 to 2012. Furthermore, we only take into account earthquakes with magnitude $\geq M_s 5.0$ and focal depth ≤ 100 km. The LMF is limited by the Curie isotherm and, therefore, cannot directly reflect magnetic/thermal structures below the Curie depth, which is about 40 km for continental crust. In different areas, earthquake selections are also dependent on intrinsic differences in seismic activity; for more details see Chapter “The vertical component B_z and tectonics.”

3 Correlations among the LMF, tectonics, and seismic activity

3.1 The surface LMF

3.1.1 The vertical component B_z and tectonics

Using the previously mentioned data and model, the surface B_z is calculated and then plotted, superimposed on the active tectonic plates, in Fig. 2. B_z is calculated using a uniform latitude and longitude grid of $0.5^\circ \times 0.5^\circ$,

while refinement of contour lines is implemented as B_z is plotted. As can be seen, B_z tends to be distributed in a stripe-like pattern with some patches occurring in certain tectonic regions. The stripes trend in the E–W direction in Central and Western China, while some are oriented in the NE–SW in Eastern China. The maximum magnitude is about 180 nT, which is only about 0.5 % of the Earth’s main field. Compared with the topography (see Fig. 1), it can be seen that obvious positive anomalies are located in the Junggar, Tarim, and Sichuan basins, and the west of the Songliao basin, while patches of second-order positive anomalies are located inside the Ordos basin and the North China Plain. Obvious negative anomalies are located along Mount Tianshan, the Himalayas, Qinling-Daba, and second-order negative anomalies are located along Mount Yinshan, Wuyi, and inside the Tibetan Plateau. This gives the general impression that positive anomalies are correlated with ancient stable basins and cratons, whereas negative anomalies are correlated with young, active orogenic belts. This coincides with MAGSAT observations, but provides a perspective with higher resolution and precision.

We also find that B_z is correlated with active tectonic boundaries. Some faults overlap in the precise location of magnetic stripes, e.g., the Himalayas fault, the Cora

Fig. 2 Surface B_z calculated with the NGDC-720 model superimposed on the active tectonic blocks (level I: solid red; level II: dashed black). Blue lines denote coasts

Kunlun-Jiali fault (the boundary between the Lhasa block and the Qiangtang block), and the North Tianshan and South Tianshan faults (the northern and southern boundaries of the Tianshan block). Some faults lie along the boundaries of the obvious anomaly areas, e.g., the West Kunlun fault (the western boundary of the Tarim block) and the Alkin fault (the southern boundary of the Tarim block) are located along the southern boundary of the Tarim positive anomaly. Some other faults are distributed along the boundaries between positive and negative anomalies, e.g., the Qinling-Dabie fault is located along the boundary between the northern and southern anomalies and the Tanlu fault is located along the boundary between the western and eastern anomalies. Faults, however, are not always correlated to surface B_z . Some level I block boundaries are not manifested clearly in surface B_z , such as the North–South Seismic Zone.

3.1.2 B_z and seismic activity

Next we studied the seismic activity. Figure 3 shows earthquakes (measured over a 10-year period) with magnitudes greater than $M_s 5.0$. In total, there are 701 seismic events, in which there are 588 events with magnitude $M_s 5.0$, 97 with magnitude $M_s 6.0$, 15 with magnitude $M_s 7.0$, and 1 with magnitude $M_s 8.0$. As is shown, the spatial distribution of earthquakes also exhibits some regularities in B_z . Earthquakes seldom occurred inside the obvious anomalies but, instead, occurred around anomaly

boundaries, e.g., the Tarim and Songliao basin positive anomaly and the Himalayas negative anomaly. Some earthquakes also occurred in the transition zones between the positive and negative anomalies, e.g., the Wenchuan earthquake and its aftershocks occurred in the transition zone between the Sichuan basin positive anomaly and the Qinling-Daba negative anomaly. Here, we call this type of regularity the “Earthquake-Magnetic Boundary Effect.” The comparison among the regions with positive and negative anomalies, shows that more earthquakes tend to occur in regions with negative anomalies. In general, larger earthquakes are more in line with the regularities above. We focus our comparisons on Mainland China, using other regions for reference.

3.1.3 Different components of the LMF, tectonics, and seismic activity

The above analyses are based solely on B_z . In this section, we also consider whether other components might have better correlations. Different LMF components are calculated and plotted in Fig. 4 according to the Gaussian coefficients of the NGDC-720 model and by using Formula (3). In order to avoid the ambiguity of relatively small earthquakes, seismic events were artificially selected, taking into account the intrinsic seismic differences between Western and Eastern China, as well as the Circum-Pacific Seismic Zone. Earthquakes with magnitude $M_s 5.0$ were retained for comparison only in Eastern China. In Western

Fig. 3 B_z at the surface and recent (2003–2012) earthquakes (black dots) with $M_s > 5.0$

China ($72^\circ < \varphi < 108^\circ$) and the southeast coast ($118^\circ < \varphi < 136^\circ$, $16^\circ < \theta < 36^\circ$), only earthquakes with magnitude greater than $M_s 6.0$ were retained. 15 earthquakes with magnitude $M_s 5.0$ remain after the selection process.

As can be seen from Fig. 4, although the main anomalies are located near the same tectonic regions, the distribution of the different components varies. Both B_x and B_y anomalies appear in magnetic stripes, but with different strikes. B_x anomaly occurs mostly along an E–W strike, and has a similar correlation as B_z with large faults. B_y anomaly mostly follows a N–S strike, and has no clear correlation with large faults except for a few N–S striking faults, e.g., the North–South Seismic Zone and the southern part of the Tanlu fault. There is

also an interesting phenomenon concerning the anomaly distribution of B_x , B_y and B_z : B_x anomalies often appear in the northern and southern side of B_z , while B_y anomalies often appear along the western and eastern side of B_z . This same phenomenon was noted, but not explained, by Kang et al. (2010). The anomalies of total intensity, B , appears to be concentrated near the Tarim, Sichuan and Songliao basins, but is scattered in other regions. With the exception of a correlation with level I block boundaries, B anomalies do not appear to be influenced by the location of faults. The distribution of earthquakes exhibits a similar regularity in different LMF components, though different LMF components show quite different spatial distributions: earthquakes seldom occurred near the centers of obvious magnetic anomalies but tend to

Fig. 4 Different components of B at the surface, plotted with recent earthquakes. Black dots denote earthquakes (see Fig. 3). **a** B_x , **b** B_y , **c** B_z , **d** B

Fig. 5 B_z at different altitudes. Black dots represent recent earthquakes. **a** $H = 50$ km, **b** $H = 100$ km, **c** $H = 200$ km, **d** $H = 400$ km

occur near the boundaries of obvious anomalies. For B_z , most earthquakes occurred in areas with negative anomalies, whereas the situations for B_x and B_y do not seem to exhibit a regular pattern.

Judged from above, the different LMF components correlate to the spatial distribution of earthquakes almost in the same level, but B_z correlates to the active tectonic blocks best. A joint study is worthy of conducting; while from here on, we will focus mainly on B_z anomalies.

3.2 The LMF at different altitudes

Magnetic anomalies come from the magnetization of rocks in the lithosphere. Although no definitive quantitative

relationship exists, since the LMFs with different wave-numbers (n in Formula 3) attenuate with different ratios according to r ($\propto r^{-(n+2)}$), the LMFs at different altitudes (thus different r values) will be manifestations of magnetic fields with different frequencies, thus corresponding to magnetic sources at different depths (Kang et al. 2012). The surface LMF is mixed with the magnetic field of near-surface magnetic minerals, thus the LMF at higher altitudes should be more closely correlated with deep tectonics and earthquakes. Below, in Fig. 5, B_z is calculated by applying Formula (3) and using altitudes of $H = 50, 100, 200$, and 400 km, respectively ($r = r_0 + H$, $r_0 = 6,371.2$ km).

When H increases, B_z shows more long-wavelength characteristics. The magnitude of B_z gradually becomes

Fig. 6 B at 200-km altitude and recent earthquakes

smaller. Meanwhile, the distribution becomes much simpler. Compared with Fig. 3, we can see that in Fig. 5, B_z decreases to about only one twentieth when H varies from 0 to 400 km (which is the orbital altitude of CHAMP). The Tarim, Sichuan, and Songliao basins always exhibit obvious positive anomalies, but these areas are enlarged gradually as H increases. Similarly, scattered negative anomalies merge together to form two huge negative-anomaly regions, which are in the Tibetan Plateau and the East Shandong-Yellow Sea. When $H = 400$ km, B_z appears in four alternating NE–SW distributions of positive and negative stripes.

Active block boundaries always manifest well in B_z at different altitudes. Surface and near-surface (Fig. 5a, b) B_z anomalies correlate best with faults of level II blocks, while they at high altitudes (Fig. 5c, d) correlate best with large faults of level I blocks, e.g., the North–South Seismic Zone is located exactly along the boundary between the west negative anomaly and the east positive anomaly when $H = 400$ km. Figure 5 also shows that the lower crust is more magnetically homogeneous than the upper crust.

For seismic activity, the same regularity is even more clear when H increases. Most earthquakes occur in regions with negative anomalies, with the exception of the 5 earthquakes with magnitude $M_s 5.0$ in the Songliao Basin. Earthquakes tend to occur on the boundaries between the positive and negative anomalies. It should be noted that Tibet is somewhat different from other regions in which earthquakes tend to manifest mostly in near-

surface B_z . But if earthquakes with larger than $M_s 7.0$ are selected, the same regularity restores. Moreover, other LMF components may be used as complementary for B_z . Taking the intensity B at an altitude of 200 km as an example, Fig. 6 shows a clearer regularity than B_z in Tibet and the nearby region, as well as in the Songliao basin. The Earthquake-Magnetic Boundary Effect is very clear.

3.3 Historical large earthquakes

In this section, we examine how well seismic activity matches with B over longer time scales. Using the earthquake catalog published by CENC we plot the distribution of earthquakes from 1970 to 2012 with $M_s > 6.0$ in Fig. 7. Taking B_z at 200 km as an example, we compare the historical seismic activity to the LMF. The destructive earthquakes with magnitudes greater than 7.0 are represented by red stars. We also mark earthquakes that invoked tremendous damage, including the 1966 Xingtai earthquake ($M_s 7.2$) and the recent 2013 Lushan earthquake ($M_s 7.0$) which occurred on April 20 in Lushan, Sichuan province.

As shown in Fig. 7, though there is a long time span between historical earthquakes and the satellite magnetic data used in the NGDC-720 model, the historical large earthquakes have an even better correlation with magnetic anomalies. First, nearly 90 % of large earthquakes occurred inside or on the boundaries of negative B_z areas, and seldom inside positive B_z areas (the area in the eastern Indian plate

Fig. 7 B_z at 200-km altitude and historical (1970–2012) large earthquakes ($M_s > 6.0$)

with positive B_z is an exception, which requires further study). Second, except for the Tibetan plateau, nearly all large earthquakes occurred on the boundaries of obvious B_z anomaly areas. Third, the situation for the earthquakes that occurred in the Tibetan plateau seems to be complicated, but for the earthquakes of $M_s > 7.0$ (red stars), the Earthquake-Magnetic Boundary Effect should be restored. This is also true for the adjacent region of China. When block boundaries coincide with magnetic anomaly boundaries, such as the Alkin fault, the East Kunlun fault, the Mani-Yushu fault (boundary between Bayan Har and Qiangtang), the Mount Longmen fault, and the Yinshan fault (north boundary of Ordos block), large earthquakes are more likely to occur in these locations.

4 Discussion

The spatial distribution of faults and seismic activity is not random in the LMF. This has also been suggested by aeromagnetic studies (e.g., Zhang et al. 2010). These correlations imply that there must be a physical mechanism that manifests the connection between the LMF and seismic activity. The LMF is composed of both a time-variable part and a time-invariable part, which corresponds to the induced magnetization and the remnant magnetization, separately. Induced magnetization tends to be most applicable for the ancient cratons, while remnant magnetization is associated remarkably with mid-oceanic ridges (Maus

and Haak 2003). Since our research focuses mainly on continental crust, we ignore remnant magnetization as a first-order approximation (Thébaud et al. 2010).

Induced magnetization is controlled by the Earth's main field, the susceptibility and the volume of magnetic rock by the equality:

$$m_1 = M_1 V = \frac{\kappa B_M}{\mu_0} V \quad (4)$$

where m_1 is the induced magnetic moment, M_1 is the intensity of magnetization, V is the volume related to the burial depth d which is assumed to be the Curie depth), B_M is the main field, μ_0 is the permeability of a vacuum, and κ is the volume susceptibility. If the main field is the dominant cause of the LMF, the other two factors can be treated as homogenous, making the distribution of B_z dependent on latitude. This is due to the fact that the vertical component of the main field is strongly dependent on latitude (see Fig. 8). Furthermore, B_z at high latitudes should be larger than B_z at low latitudes, but this is not apparent in Fig. 7, suggesting that the Earth's main field plays only a secondary role in the generation of the LMF.

The other two factors are the susceptibility κ and Curie depth d . Different types of rocks have different susceptibility values, and usually it is found (Xu 2009) that:

$$\kappa_{\text{igneous rock}} \gg \kappa_{\text{metamorphic rock}} \gg \kappa_{\text{sedimentary rock}} \quad (5)$$

The susceptibility is determined by rocks in the whole crust, which is not easily to be measured. Judging from

Fig. 8 The vertical component of the Earth's main magnetic field by the IGRF-11 model

rock outcrops, κ is unlikely to be the dominant factor of the LMF. For example, limestone is widespread in Yangtze craton (in the northwest of South China block), while granite is widespread in Cathaysian landmass (in the southeast of South China block) (Zhou and Li 2000). Thus by Formulas (4) and (5), B_z in Yangtze craton should be larger than that in Cathaysian landmass. On the contrary, B_z is positive in Yangtze craton, and negative in Cathaysian landmass in Fig. 5.

So the only remaining dominant factor is the Curie depth. The Curie depth is a thermal boundary, while it could be reflected via the LMF. Thus, we can compare the surface heat flow with the LMF to check whether the Curie depth is dominant. The heat flow of Mainland China could be found in many publications, such as (Hu et al. 2000).

Comparing Fig. 5 with the heat flux (Fig. 6 in Hu et al. 2000), we find that the surface heat flow is closely correlated with B_z at 200 km. High heat flow areas, e.g., the Tibetan Plateau, the Chuandian block, and the Cathaysian plate, usually correspond to obvious negative anomalies, while low heat flow areas, e.g., the Tarim, Junggar, Sichuan, and west Songliao basin, usually correspond to obvious positive anomalies. Higher heat flow makes the Curie depth shallower and, thus, exhibits negative anomalies.

This indicates that variations in the Curie depth are a dominant reason for different LMFs in the research area.

Two nearby blocks with obviously different LMFs may have remarkably different Curie depths and, thus, different temperature distributions in the deep crust. The stress state and rheological parameters are of vital importance for the spatial distribution of earthquakes, both of which are very sensitive to temperature (Shi and Cao 2008). Underground stress and viscosity are not easily observed directly, but the different LMFs of blocks may be an indicator of different stress states or viscosities. The boundaries of obvious magnetic anomalies may also coincide with the boundaries of obvious variations in stress or viscosity. For this reason, large faults and earthquakes tend to occur in these areas. The correlation between the Curie depth and seismic activity is also supported by other research (Rajaram et al. 2009). Compared with B_x and B_y , B_z is more sensitive to the Curie depth, thus more correlated to the active tectonic blocks.

5 Conclusions

Plates and active tectonic blocks are not the only parameters that can be used to define the spatial distribution of

earthquakes. According to our research, the LMF can also provide constraints on seismic activity. Large faults and earthquakes tend to occur on the boundaries of obvious magnetic anomalies, which is named the “Earthquake-Magnetic Boundary Effect” in this research. We studied various components of the LMF at different altitudes and found a strong correlation between B_z at 200 km and seismic activity. The distribution of the LMF is predominantly affected by the Curie depth, which is related to the distribution of the stress state and viscosity via differences in temperature.

The correlation between earthquakes and the LMF maybe no stronger than that between earthquakes and active tectonic blocks, thus we cannot constrain the spatial distribution of earthquakes uniquely by the LMF. However, the LMF does provide distinct and additional constraint on distributions of earthquakes. With more comprehensive studies about the correlation between earthquakes and tectonics, the LMF, the gravity field, heat flux, etc., we may understand the spatial distribution regularity of earthquakes much better.

This study may be instrumental in future earthquake monitoring and disaster prevention, if we strengthen monitoring on the boundaries of obvious magnetic anomalies, or plan to construct important municipal buildings far away from those boundaries.

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