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Seismomagnetic research in Beijing and its adjacent area, China

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Abstract

During 1993–2002, a field experiment in the Miyun reservoir was carried out. A relation coefficient of −0.063 nT/m was obtained between geomagnetic changes and water depth variations in the reservoir, which agrees with piezomagnetism. The tectonomagnetic investigations suggested static and dynamic tectonomagnetic effects of the active faults. These effects provide useful information for monitoring the potential earthquakes in and near the active faults in the future. The seismomagnetic observation and research in Beijing and its adjacent area show that seismomagnetic precursors are a near-field effect, the anomalous amplitude is 2–11 nT, and the precursor time is several days to one year. These results could be applied in earthquake prediction study.

Keywords: Piezomagnetic experiment; Active fault; Tectonomagnetic effect; Seismomagnetic precursor; Beijing of China

1. Introduction

Since Nagata (1969) proposed the tectonomagnetism, many seismomagnetic observations and researches have been carried out, and great progress has been obtained. Johnston (1997) comprehensively reviewed the electric and magnetic fields accompanying seismic and volcanic activities. Local magnetic field changes which accompany moderate or large earthquakes have been observed in the seismic-active areas over the world (Smith and Johnston, 1976; Rikitake and Honkura, 1985; Shapiro and Abdullabekov, 1982; Davis and Johnston, 1983; Sumitomo and Noritomi, 1986; Johnston and Mueller, 1987; Johnston, 1989; Zhan, 1989; Oshiman et al., 1991; Johnston et al., 1994; Iyemori et al., 1996; Mueller and Johnston, 1998; Uyeda and Park, 2002; Hayakawa and Molchanov, 2002; Matsushima et al., 2002; Hayakawa, 2004; Okubo and Oshiman, 2004; Ujihara et al., 2004; Yen et al., 2004). In the study of earthquake prediction, there were some examples for earthquake prediction test by using the method of seismomagnetic precursors (Johnston et al., 1985; Sasai and Ishikawa, 1991; Shapiro et al., 1994; Zhan et al., 1999).

Beijing and its adjacent area are located in the Yanshan seismic belt, which is one of the most active seismic belts in China. In the history, more than 80 earthquakes with $M > 5.0$ occurred, among which one with $M = 8.0$, five earthquakes with $M = 7.0$–7.9 and 23 earthquakes with $M = 6.0$–6.9. The biggest earthquake with $M = 8.0$ (September 2, 1679) in the Yanshan belt just occurred in this area. In order to monitor the seismic activity in this area, seismomagnetic observations and research have been carried out since 1975.

This paper describes the seismomagnetic research in Beijing and its adjacent area, including the experiment in the Miyun reservoir, the tectonomagnetic investigation of active faults and the seismomagnetic study in Beijing and its adjacent area.

2. Piezomagnetic experiment around the Miyun reservoir

The Miyun reservoir is located in the north area of Beijing and was built in 1960. Its maximum volume of water storage is $4.375 \times 10^9\ m^3$. The north part of the reservoir is shallow and the south part is deep. The maximum depth is 63.5 m.

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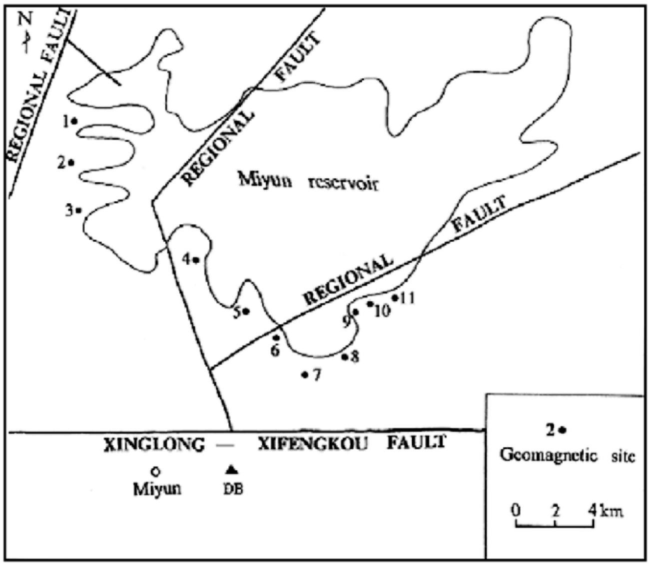

Fig. 1. Location of geomagnetic sites, station DB and faults around the Miyun reservoir.

In order to understand the physical basis of seismomagnetic effect, we carried out a field experiment during the water storage process in the Miyun reservoir. We carefully selected 11 sites around the reservoir (Fig. 1). In Fig. 1, the station DB is a geomagnetic reference one, which is 10 km apart from the reservoir. The condition around each site and station DB is good without any electromagnetic noise and with low magnetic gradient (<5 nT/m). In order to ensure the sensor of the magnetometer set up at the same position of each site and the station DB for various survey time, a permanent mark was set up at each site and the station DB.

Seven surveys were carried out during 1993–2002. G-856 magnetometer is used to measure the total intensity F of the geomagnetic field, the resolution is 0.1 nT and the accuracy is 0.5 nT. In each survey, a recording magnetometer (the resolution is 0.1 nT and the accuracy is 0.5 nT) provided by the US Geological Survey with 2 m sensor staff was set up at the station DB and F was continually observed with 2-min sampling for 3–5 days. At each site, G-856 magnetometer with 2 m sensor staff was set up. F was observed with 2-min sampling for 20–60 min at each site simultaneously with the observation at the station DB. The geomagnetic data at each site were reduced by using the data at station DB. The reduced date of each survey is listed in Table 1. The mean standard deviation of geomagnetic reduced values is 0.31 nT. This shows that the geomagnetic survey data are reliable and accurate.

Taking the water depth H_0 and the water storage volume V_0 in the Miyun reservoir on September 24, 2002 as the reference values, we calculated the relative water depth h and the relative water volume v related to the reference values:

$$h = H - H_0 \tag{1}$$

$$v = V - V_0 \tag{2}$$

where H and V represent the water depth and the water storage volume in the reservoir on each reduced date, respectively. Table 1 lists the values of h and v on various reduced date and shows that the maximum change of water depth in the reservoir is 15.54 m during 1993–2002.

We processed the above geomagnetic survey data at each site related to the data F_0 at the station DB:

$$f = F - F_0 \tag{3}$$

where f and F, respectively, represent the relative geomagnetic change and the reduced value at each site, and F_0 represents the observational value at various reduced time at the station DB.

Using the least square method, we analyzed the relationship between the relative geomagnetic change f and the relative water depth h, and the relative water volume v in the Miyun reservoir:

$$f = f_0 + \alpha h \tag{4}$$

where α represents a relation coefficient between the relative geomagnetic change f and the relative water depth h in the reservoir

$$f = f_0 + \beta v \tag{5}$$

where β represents a relation coefficient between the relative geomagnetic change f and the relative water volume v in the reservoir.

Table 1
Reduced date for all geomagnetic surveys, relative water depth h and relative water volume v in the Miyun reservoir

Survey number	1	2	3	4	5	6	7
Reduced date	1993 Oct. 11	1994 May 29	1995 May 28	1996 May 18	1997 June 25	1998 Oct. 17	2002 Sep. 24
h (m)	12.37	10.00	15.54	14.08	13.47	14.51	0.00
v (10^8 m^3)	14.10	10.86	19.42	16.88	16.22	17.80	0.00

Table 2
Relation coefficients α and β at various sites around Miyun reservoir

Site number	1	2	3	4	5	6	7	8	9	10	11
α (nT/m)	−0.052	−0.055	−0.050	−0.058	−0.064	−0.068	−0.076	−0.071	−0.070	−0.067	−0.062
β (10^{-8} nT/m^3)	−0.044	−0.045	−0.042	−0.048	−0.051	−0.059	−0.062	−0.056	−0.059	−0.054	0.051

Table 2 shows the above analysis results. The mean value of the relation coefficient obtained from Table 2 is

$$\alpha = -(0.063 \pm 0.008)\ \mathrm{nT/m}$$
$$\beta = -(0.052 \pm 0.007) \times 10^{-8}\ \mathrm{nT/m^3}$$

These results show that there is a negative relationship between the geomagnetic changes and the water storage variations in the Miyun reservoir.

3. Tectonomagnetic investigations of active faults

The Babaoshan fault, the Xiadian fault and the Zijinguan fault are active faults in Beijing and its adjacent area. Table 3 lists character and properties of these active faults. Several strong earthquakes occurred in these faults and their adjacent areas. The biggest one in the Babaoshan active fault was the $M = 6.5$ earthquake in 1730; that in the Xiadian active fault was the $M = 8.0$ in 1679; and the one in Zijinguan active fault was the $M = 6.8$ in 1720.

3.1. Zijinguan active fault

In order to study the tectonomagnetic effect of the Zijinguan active fault, a geomagnetic network consisting of nine profiles with 528 sites and five temporary stations was set up in and near this fault (Fig. 2(a)). The distance between the adjacent profiles is 10–130 m. The distance between the adjacent sites in a profile is 4 m.

Table 3
Character and properties of the active faults

Fault	Length (km)	Dip-strike	Type	Active rate
Babaoshan fault	130	NE/SE∠68°	Normal	0.1–0.2 mm/year
Xiadian fault	120	NE/SE∠75°	Normal	0.3–0.76 mm/year
Zijinguan fault	102	NE/SE∠65°	Normal	0.17–0.44 mm/year

Using proton procession magnetometer, the total intensity F of geomagnetic field was observed. The recording magnetometers provided by the US Geological Survey were set up at temporary stations CO, NE and NW (Fig. 2(a)), F was synchronously observed with 2-min sampling. G-856 magnetometers were set up at temporary stations SE and SW, and F was synchronously observed with 6-s sampling. G-816 magnetometers were used to measure F at each site. According to the data at the temporary station CO, the geomagnetic data at various sites were reduced.

Taking the station CO as the geomagnetic reference one, we processed the above reduced value F at various sites:

$$f = F - F_0 \tag{6}$$

where F_0 represents the observational value at reduced time at the station CO. Using f values at various sites, the magnetic distribution in the Zijinguan active fault and its adjacent area is shown in Fig. 2(b). Fig. 2(b) shows that magnetic field at both sides E and W of the active fault is negative. Magnetic field along the active fault is positive. From Fig. 2(b) it is seen that there is an obvious relationship between the distribution of magnetic field and the Zijinguan active fault. The magnetic field related to the Zijinguan active fault is estimated as about 100 nT. This is the effect of a static state, and we define it as the static tectonomagnetic effect. Therefore, the static tectonomagnetic effect of the Zijinguan active fault is about 100 nT.

According to the synchronous observation geomagnetic data with 2-min sampling at the stations NE and NW, geomagnetic variations at the two stations were consistent very well; the synchronous difference was quite stable, the standard deviation is 0.29 nT. The analysis result shows that

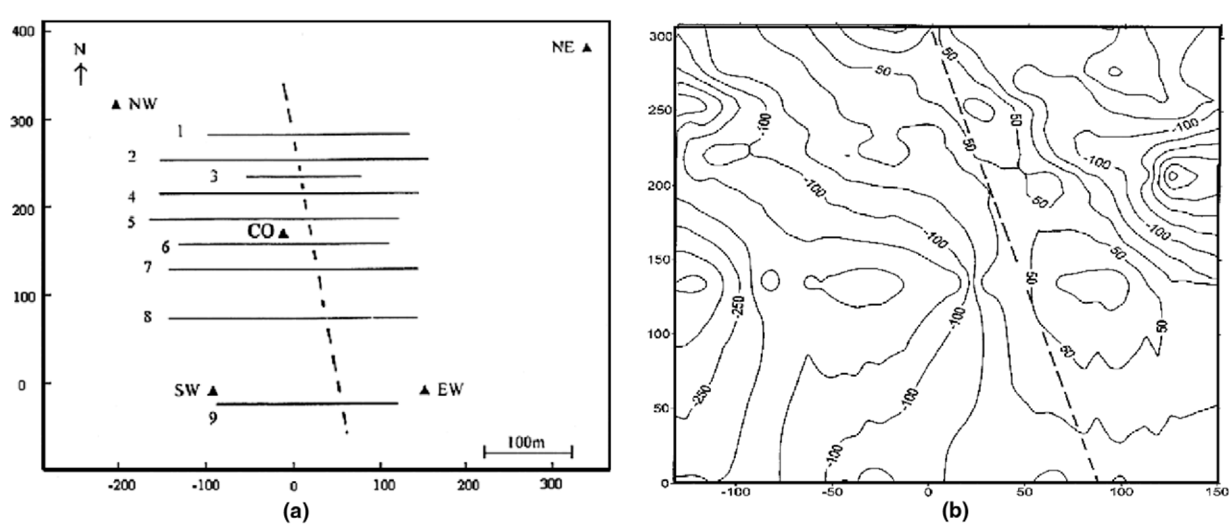

Fig. 2. (a) Location of geomagnetic stations (triangle) and profiles (digit) across the Zijinguan active fault (dashed line). (b) Distribution of magnetic field in and near the Zijinguan active fault (dashed line). The difference between the adjacent isolines is 50 nT. The location in (b) is the same with that in (a), the scale is also the same with that in (a), the unit is one meter.

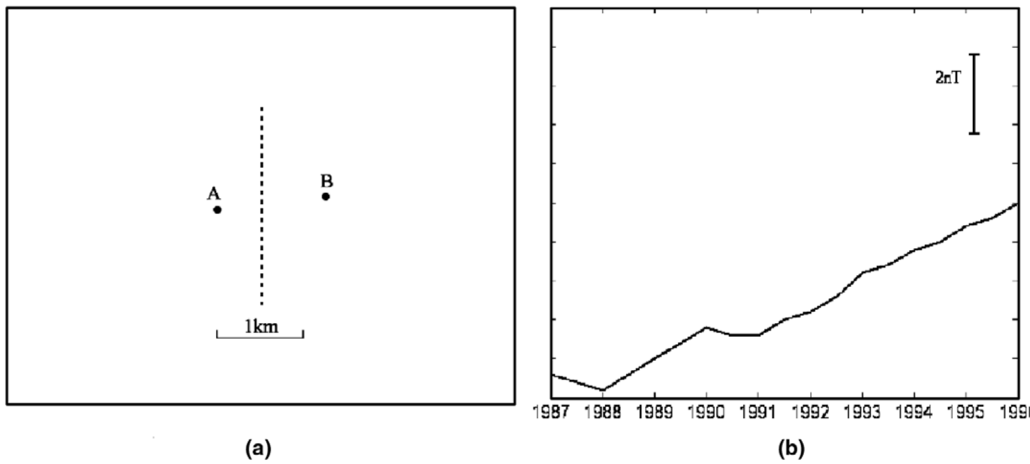

Fig. 3. (a) Location of geomagnetic sites A and B near the Zijinguan active fault (dashed line). (b) Change of the geomagnetic difference between sites A and B during 1987–1996.

there is a difference of 0.7 nT in the amplitude of daily variation between the stations NE and NW.

Using the fast Fourier transform (FFT) method, we analyzed the geomagnetic data with 2-min sampling at the stations NE and NW, and the data with 6-s sampling at the stations SE and SW. The FFT results show that geomagnetic spectrum on the side E and the side W of the Zijinguan active fault is quite consistent, without any obvious difference.

Fig. 3(a) shows location of geomagnetic sites near the Zijinguan active fault. Using the proton magnetometer, we observed geomagnetic total intensity F; the mean standard deviation of the geomagnetic data is 0.63 nT. Fig. 3(b) shows the change of the geomagnetic difference f between sites A and B (Fig. 3(a)) during 1987–1996. From Fig. 3(b) it is seen that the amplitude of the f change is 2.4 nT during 1987–1996. The distance between the site A and B is only 1.3 km. In general condition, the geomagnetic changes at two sites with a separation of 1.3 km are the same. The change of the f with 2.4 nT is related to the Zijinguan active fault. This is the effect of a dynamic state, and we define it as the dynamic tectonomagnetic effect. Therefore, the dynamic tectonomagnetic effect of the Zijinguan active fault is 2.4 nT.

3.2. Babaoshan active fault

In the geomagnetic network in the Dahuichang area, there are the station DH, three profiles (see Fig. 4(a)) and 51 sites. The separation between the adjacent profiles is 100 m. The separation between the adjacent sites along the profiles is 25 m.

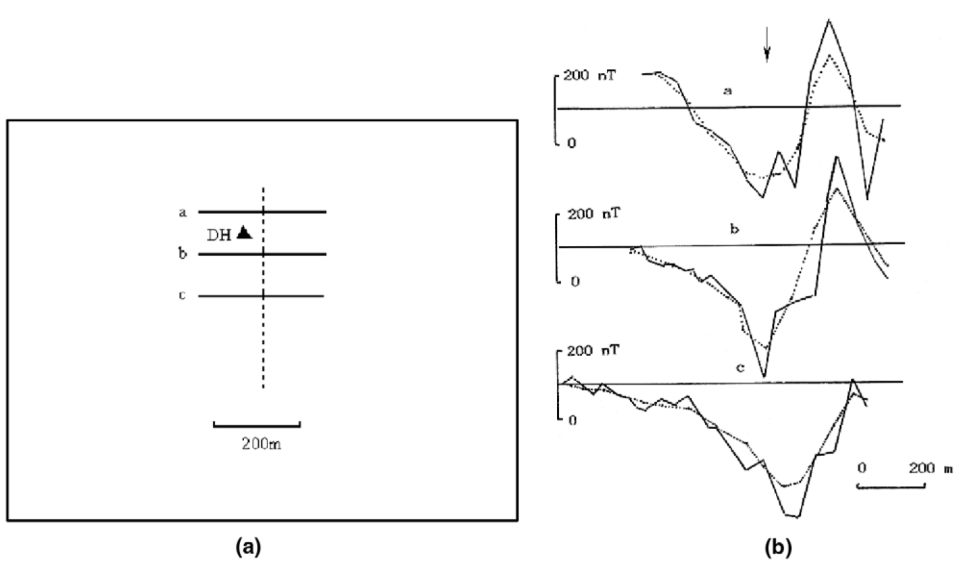

Fig. 4. (a) Location of geomagnetic station DH, profiles a, b and c across the Babaoshan active fault (dashed line). (b) Magnetic changes at profiles a, b and c across the Babaoshan active fault, the solid line represents the geomagnetic value f, the dashed line represents the 3-point running f value. The arrow represents location of the Babaoshan active fault.

Using the proton procession magnetometer, the total intensity F of geomagnetic field was observed. The magnetometer was set up at temporary station DH for observation with 1-min sampling. According to the data at the temporary station DH, the geomagnetic data at various sites were reduced.

Taking the station DH as the geomagnetic reference one, we processed the reduced value F at various sites:

$$f = F - F_0 \tag{7}$$

where F_0 represents the observational value at the reduced time at station DH. Using f values at various sites, the magnetic changes at profiles a, b and c across the Babaoshan active fault are shown in Fig. 4(b). Fig. 4(b) shows that the amplitudes of magnetic changes at profiles a, b and c are respectively about 300 nT, 400 nT and 200 nT. It is seen from Fig. 4(b) that there is an obvious relationship between the magnetic changes and the Babaoshan active fault. The magnetic field related to the active fault is estimated as ~200 nT. It is the effect of a static state, and we define it as the static tectonomagnetic effect. Therefore, the static tectonomagnetic effect of the Babaoshan active fault is ~200 nT.

Fig. 5(a) shows the location of stations KL and WO near the Babaoshan active fault. We observed the geomagnetic total intensity F twice per year at stations KL and WO. For various observations, the recording magnetometers were set up at stations KL and WO; F was simultaneously observed with 2-min sampling at these stations for 3 days. The mean standard deviation of simultaneously difference between two stations is 0.25 nT.

Fig. 5(b) shows the magnetic change of the geomagnetic difference f between stations KL and WO during 1987–1996. It is seen from Fig. 5(b) that the amplitude of the f change is 3.2 nT during 1987–1996. The separation between stations KL and WO is only 1.6 km. In general condition, the geomagnetic changes at two stations with a separation of 1.6 km are the same. The change of f with 3.2 nT is related to the Babaoshan active fault. This is the effect of a dynamic state, defining it as the dynamic tectonomagnetic effect. Therefore, the dynamic tectonomagnetic effect of the Babaoshan fault is 3.2 nT.

3.3. Xiadian active fault

In the geomagnetic network in Xiadian area for the Xiadian active fault, there are 45 sites, the station XD and three profiles across the Xiadian active fault. The distance between the adjacent profiles is 100 m. The distance between the adjacent sites along the profiles is 25 m.

Using the proton procession magnetometer, the total intensity F of geomagnetic field was observed. According to the data at the temporary station XD, the geomagnetic data at various sites were reduced.

Taking the station XD as the geomagnetic reference one, we processed and analyzed the reduced value at various sites. The results show that the static tectonomagnetic effect of the Xiadian active fault is about 20 nT.

We observed the geomagnetic total intensity F twice per year at stations DS and MQ, which are located respectively in sides E and W of the Xiadian active fault. The distance between stations DS and MQ is only 1.8 km. For various observations, the recording magnetometers were set up at stations DS and MQ; F was simultaneously observed with 2-min sampling at these stations for 3 days. The mean standard deviation of simultaneously difference between two stations is 0.28 nT. The geomagnetic data at stations DS and MQ during 1987–1996 were analyzed. The results show that the dynamic tectonomagnetic effect of the Xiadian active fault is 4.0 nT.

4. Seismomagnetic observation and research in Beijing and its adjacent area

4.1. Seismomagnetic precursor information

Since the $M = 7.3$ Haicheng earthquake on February 4, 1975 in Liaoning province of China, seismomagnetic

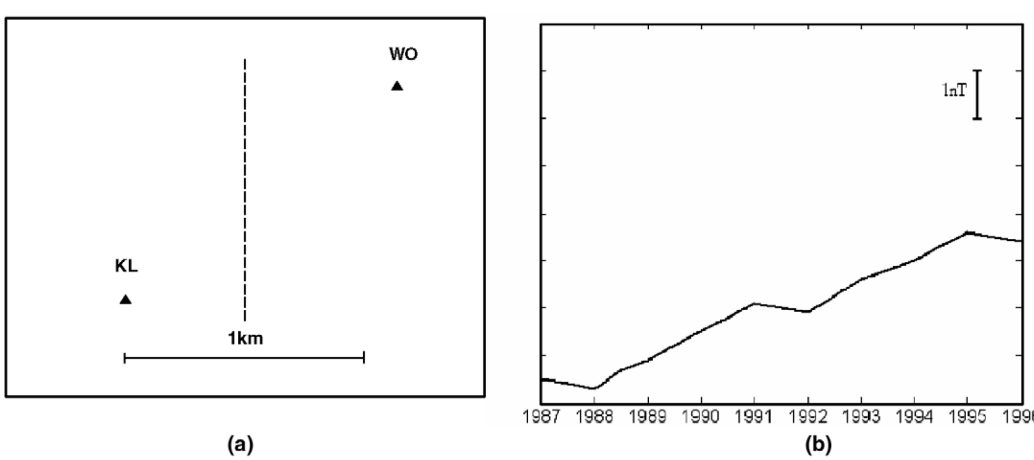

Fig. 5. (a) Location of stations KL and WO near the Babaoshan active fault (dashed line). (b) Magnetic change of the geomagnetic difference between stations KL and WO during 1987–1996.

observations have been carried out in order to monitor the seismic activities and to investigate the seismomagnetic precursors in Beijing and its adjacent area.

Fig. 6(a) shows the location of geomagnetic observatories, sites and the epicenter of $M = 7.8$ Tangshan earthquake on July 28, 1976. Three components of the geomagnetic field are observed at the observatories, the standard deviations of geomagnetic data are 1.5 nT and 2.0 nT, respectively, for the total intensity F and the vertical component Z. F and Z were observed at various sites. The mean standard deviations of the survey data at various sites are 2.0 nT for F and 2.5 nT for Z.

The geomagnetic data at the observatories and sites shown in Fig. 6(a) were processed and analyzed. The results show that there were geomagnetic anomalies at some observatories and sites. As an example, Fig. 6(b) shows the changes of the geomagnetic total intensity F at site 3 and of the vertical component Z at the observatory CL during 1973–1980. It is seen from Fig. 6(b) that the anomaly of F was observed at site 3 before the $M = 7.8$ Tangshan earthquake (July 28, 1976). The anomalous value of F is 8 nT at site 3 which is 50 km apart from the epicenter. Precursory time of F is about one year before the $M = 7.8$ earthquake. The anomaly of Z was observed at observatory CL before the $M = 7.8$ earthquake. The anomalous value of Z is 10 nT at observatory CL which is 70 km apart from the epicenter. Precursory time of Z is about one year before the $M = 7.8$ earthquake.

According to the precursory changes at the observatories and sites in Fig. 6(a) (Zhan, 1988; Sun and Lu, 1982; Zhan et al., 1990), the seismomagnetic changes for the $M = 7.8$ Tangshan earthquake (July 28, 1976) are shown in Fig. 7. It is seen from Fig. 7 that there are seismomagnetic changes of 11 nT and 9 nT, respectively, in the vertical component (Fig. 7(a)) and in the total intensity (Fig. 7(b)) near the epicenter.

Fig. 8(a) shows the location of geomagnetic sites and the $M = 4.5$ Baodi earthquake (November 18, 1993). We analyzed the geomagnetic data at these sites, the standard deviation of the survey data is 1.0 nT. The result is shown in

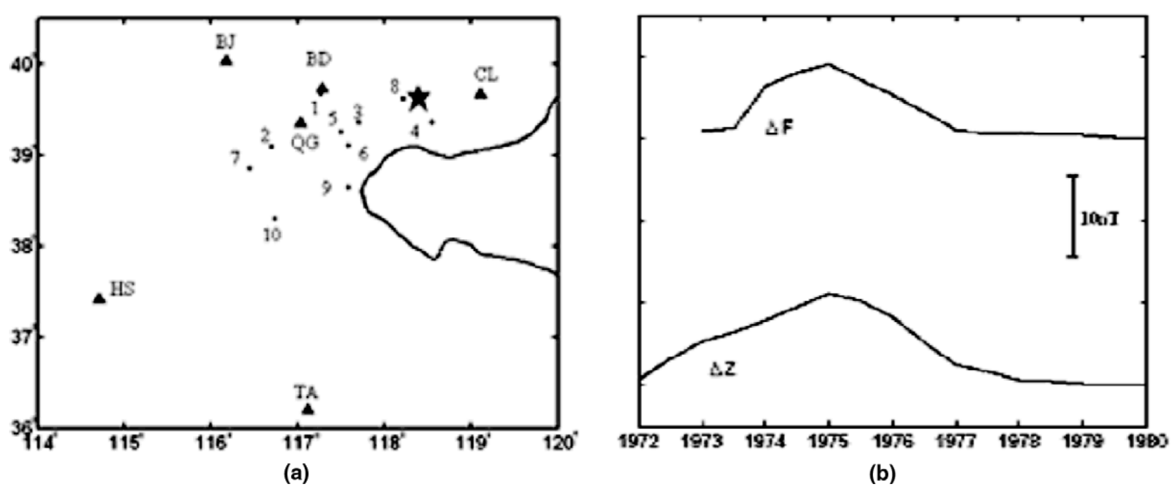

Fig. 6. (a) Location of geomagnetic observatories (triangle), sites (dot) and the epicenter of $M = 7.8$ Tangshan earthquake (star). (b) Changes of geomagnetic total intensity ΔF at site 3 and vertical component ΔZ at the observatory CL (unit: nT).

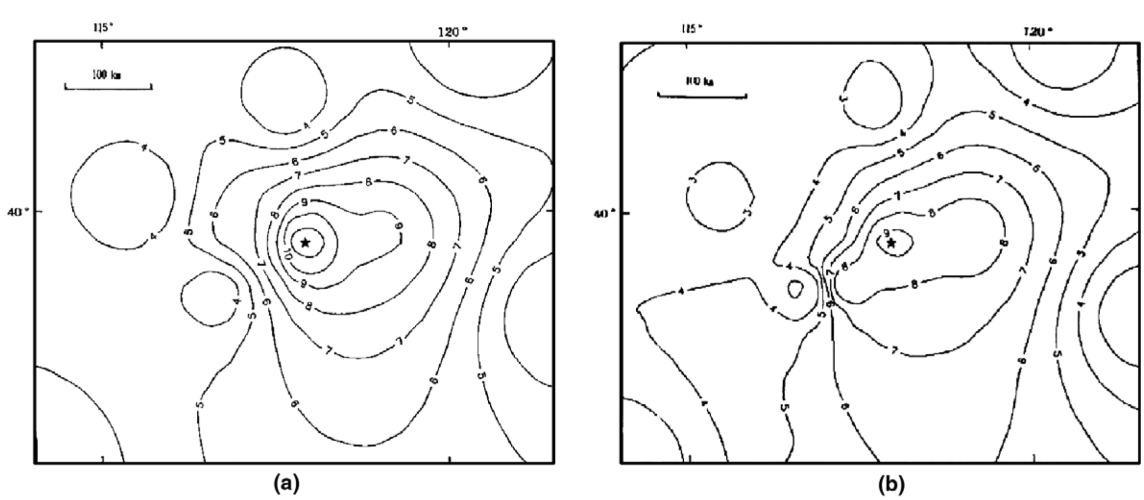

Fig. 7. Contours of seismomagnetic changes for the $M = 7.8$ Tangshan earthquake, July 28, 1976: (a) ΔZ (unit: nT); (b) ΔF (unit: nT).

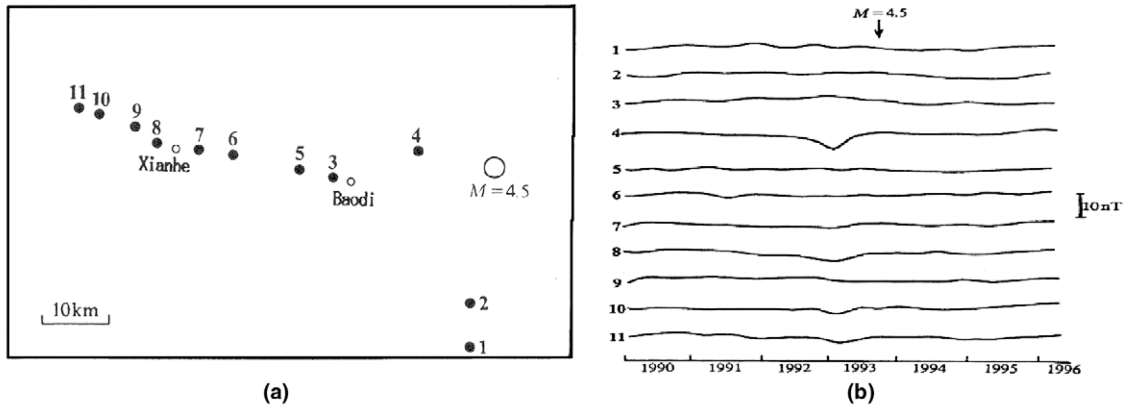

Fig. 8. (a) Location of geomagnetic sites and the $M = 4.5$ Baodi earthquake (November 18, 1993). (b) Changes of geomagnetic total intensity at various sites during 1990–1996. Arrow represents the occurring time of the $M = 4.5$ earthquake.

Table 4
Seismomagnetic precursors in Beijing and its adjacent area

Date	Location	M	d (km)	T	f (nT)
1976.07.28	Tangshan	7.8	20–150	~1 year	11–3
1982.12.10	Madaoyu	4.9	30–50	2 months	2–3
1989.10.18	Datong	6.0	64	6 months	11
1990.9.22	Xiaotangshan	3.7	2	7 days	3
1993.11.18	Baodi	4.5	10	7 months	5.2
1995.7.20	Huailai	4.3	15	3 months	4.5
1996.5.3	Baotao	6.4	100	6 months	7
1996.12.16	Shunyi	4.0	10	5 days	3
1998.1.10	Zhangbai	6.2	120	8 months	10
1998.7.28	Baodi	3.8	10	40 days	3

Fig. 8(b). Fig. 8(b) shows the change of the geomagnetic total intensity occurred at site 4 before the $M = 4.5$ earthquake. Site 4 is 10 km apart from the epicenter and is the nearest one. The precursory anomaly is 5.2 nT and the precursory time is 7 months.

Table 4 lists the seismomagnetic precursors observed in Beijing and its adjacent area. In Table 4, M is the earthquake magnitude, d is the distance from the epicenter, T is the precursory time, and f is the anomalous amplitude of geomagnetic field. It is seen in Table 4 that the earthquake magnitude is 3.7–7.8, the epicenter distance is 2–150 km, the precursory time is a few days to one year, and the seismomagnetic amplitude is 2–11 nT.

4.2. Short-period seismomagnetic information

In the geomagnetic network in Beijing and its adjacent area, there are seven temporary stations (Fig. 9(a)). In order to ensure the sensor of the magnetometer set up at the same position of each station for various observations, a permanent mark was set up at each station. The condition around each station is good without any electromagnetic noise and with low magnetic gradient (<5 nT/m). Using the recording magnetometer, we observed the geomagnetic total intensity F one or twice per year at the temporary stations. For various observations, the magnetometer was set up at each station; F was simultaneously observed with 2-min sampling at these stations for 3–5 days. The mean standard deviation of simultaneously difference between two stations is 0.45 nT.

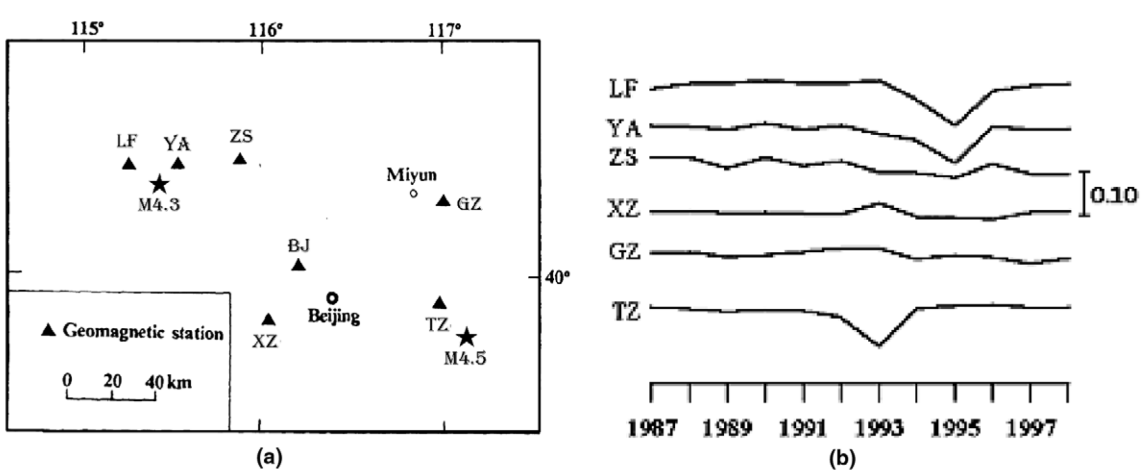

Fig. 9. (a) Location of geomagnetic stations and the earthquake epicenters. (b) Changes of the ratio of the FFT amplitude at various stations related to the amplitude at station BJ for period $T = 4.3$ h during 1987–1997.

In order to analyze the spectral characters of geomagnetic variations, we analyzed the above simultaneous data with 2-min sampling at various temporary stations in the same duration by using the fast Fourier transform (FFT) method. The changes of the spectrum amplitude A with the period T were obtained by using the FFT analysis. There was a decreasing tendency of the spectrum amplitude A with the decreasing of period; the geomagnetic spectrums at various temporary stations have good consistency.

In order to study the short-period seismomagnetic information, we calculate the ratio α of the FFT amplitude at various temporary stations related to the amplitude at station BJ in the same duration for the same period:

$$\alpha = A/A_0 \tag{8}$$

where A and A_0 are the amplitudes of FFT spectrum, respectively, at various stations and at station BJ for the same period.

We analyzed the changes of the ratio α of the FFT amplitude at various stations during 1987–1997. The results show that the anomaly of the ratio α only occurred for the period $T = 4.3$ h at some stations. There was no anomaly for $T = 4.3$ h at other stations and no anomaly in other periods.

Fig. 9(b) shows the ratio α of the FFT amplitude at various temporary stations related to the amplitude at station BJ for period $T = 4.3$ h during 1987–1997. It is seen from Fig. 9(b) that the curve of the ratio α at various stations is stable. However, the ratio α in station TZ in 1993 decreases, and the relative decrease amplitude is about 10%. The ratio α in the stations LF and YA in 1995 decreases and the relative decrease amplitude is 10%. These changes are obvious. It is seen in Fig. 9(a) that there are two earthquakes, the $M = 4.5$ Baodi earthquake on November 18, 1993 which is about 30 km apart from the station TZ, and the $M = 4.3$ Huailai earthquake on July 20, 1995 which is about 20 km apart from the stations YA and LF; and the other stations are far from the two earthquakes. Therefore, the time–space changes of the ratio α are related to the two earthquakes.

5. Discussion and conclusions

(1) Table 5 shows the comparison between the experiment results obtained in this paper and others. The relation coefficients in the Talbingo reservoir, Australia, and the Charvak reservoir, former USSR, were calculated according to the results, respectively, obtained by Davis and Stacey (1972) and Shapiro et al. (1978). It is seen from Table 5 that all the relation coefficients are negative. It means there does exists a negative relationship between the geomagnetic changes and the water storage variations in the reservoir. The relation coefficients obtained in this paper are close to those in other reservoirs.

We collected rock samples near the geomagnetic sites around the Miyun reservoir. The measurement of the rock magnetism showed that the susceptibility of rock samples is in the range of 10^{-4}–10^{-2}, showing the rock magnetism is stronger. According to piezomagnetism, the magnetization of rock changes with loading. When the pressure increases, the magnetization in the direction parallel to the pressure decreases; while that in the direction perpendicular to the pressure increases. The water storage variation in the reservoir is equivalent to the change of the water pressure on magnetic rock under the reservoir. When the water level in the reservoir rises, the compressive stress in the vertical direction in rock layer increases. The average of the geomagnetic inclination in the Miyun reservoir is about 58°. Therefore, the vertical component of rock magnetization is greater than the horizontal one. It is obtained that the geomagnetic total intensity decreases somewhat when the compressive stress in the vertical direction increases. The negative relationship between the geomagnetic changes and the water storage variations in the Miyun reservoir is a verification of the piezomagnetism of rock.

The underground stress changes caused by the slow water storage variations in the reservoir are similar to the slow changes of the underground stress during the earthquake preparation process. Therefore, the experiment in the Miyun reservoir provides a good simulation of seismomagnetic effect and could be applied in earthquake prediction study by the geomagnetism method.

(2) Table 6 shows the tectonomagnetic effects and the seismic activities of the active faults, where M represents the magnitude of the biggest earthquake occurred in the active faults and their adjacent areas in the history. The static tectonomagnetic effects of the active faults are closely related to the features of the active faults and the electromagnetic features of the underground media. The dynamic tectonomagnetic effects of the active faults are related to many factors, such as the fault activity, the changes of the underground stress, the seismic activities, etc.

Earthquakes generally occur in and around the active faults. Therefore, the tectonomagnetic investigation on active fault is directly related to the research on earthquake mechanism. Moreover, it also has important significance in

Table 5
Comparison between the experiment results obtained in this paper and others

Reservoir	Max. depth (m)	M	Time	N	α (nT/m)	β (10^{-8} nT/m^3)	References
Miyun (China)	63.5	11	1993–2002	7	-0.063 ± 0.008	-0.052 ± 0.007	This paper
Talbingo (Australia)	140	16	1971–1972	15	-0.025		Davis and Stacey (1972)
Charvak (USSR)		35	1975	10–15		-1.09	Shapiro et al. (1978)
			1976	10–15		-0.71	
New Melones (USA)	108	6			-0.04 ± 0.02		Zhan (1987)

Table 6
Tectonomagnetic effects and seismic activities of the active faults

Fault	Static effect (nT)	Dynamic effect (nT)	M
Babaoshan fault	∼200	3.2	6.0
Xiadian fault	∼20	4.0	8.0
Zijinguan fault	∼100	2.4	6.75

geodynamics research. The research results on seismic activity show that there would be some earthquakes with $M = 6$–8 in the areas of the Babaoshan fault, the Xiadian fault and the Zijinguan fault in the future (Zhang and Mao, 1996). Therefore, the research results on the abovementioned tectonomagnetic effects of the active faults provide a basis for monitoring the potential earthquake risk in the future.

(3) The results of the seismomagnetic research in Beijing and its adjacent area show that the seismomagnetic precursor is a near-field effect, the anomalous amplitude is 2–11 nT, and the precursor time is several days to one year. These results could be applied in earthquake prediction study.

Theoretical research and field observations show that underground conductivity will change during the earthquake preparation process and it produces a magnetic effect induced by earthquakes, i.e. the induction magnetic effect (Rikitake, 1976; Qi et al., 1981). The short-period seismomagnetic information shown in Fig. 9 should belong to the induction magnetic effect, and agrees with the seismomagnetic precursors for the $M = 4.5$ Baodi earthquake on November 18, 1993 and the $M = 4.3$ Huailai earthquake on July 20, 1995 shown in Table 4 and Fig. 8. This agreement further increases the reliability of the seismomagnetic changes.

At present, the earthquake prediction level by using the geomagnetic method is relatively lower and is still at the stage of accumulating data and test research. Therefore, we should strengthen the observation and research of the seismomagnetic precursor and the study on the seimomagnetic mechanism, and actively combine these investigations with the research of other precursors, such as earthquake, deformation, gravity, geoelectricity, stress, groundwater, etc.

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