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Results of Geomagnetic Studies on the Problem of Forecasting Strong Earthquakes in Uzbekistan

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Abstract

The article is devoted to the problem of forecasting strong earthquakes by the geomagnetic method. The geomagnetic method is widely used on this problem in seismically active regions of the world as one of the promising, informative and operational geophysical methods. The results of long-term geomagnetic studies on the problem of forecasting strong earthquakes in Uzbekistan are presented. Geomagnetic studies were carried out on the territories of the Tashkent, Ferghana, and Kyzylkum geodynamic polygons in the epicentral zones of strong earthquakes that occurred. Long-term, medium- and short-term precursors of earthquakes have been identified. Anomalous changes in the geomagnetic field associated with the decline in aftershock activity were also revealed. The dependence between the duration of the manifestation of long-term magnetic precursors and the magnitude of earthquakes is determined. Absolute proton magnetometers MMP-1, MV-01 (Russia), and G-856 (USA) were used to measure the geomagnetic field.

Keywords

Geodynamic Polygon, Geomagnetic Field Anomaly, Earthquake Precursor, Magnitude, Epicenter, Magnetic Station, Magnetometer

1. Introduction

Strong earthquakes lead to numerous victims among the population and major material damage. The last event is the strong earthquakes of February 6, 2023, on the territory of Turkey with M = 7.4 - 7.8 and their aftershocks, which led to thousands of human casualties and major destruction in the territories of Turkey and Syria. Today, despite large-scale geological and geophysical studies in seismically active regions of the world, the problem of forecasting strong earthquakes has not been solved. The successes of the last fifty years of research can be noted: the identification of reliable earthquake precursors, the establishment of the location and strength of possible strong earthquakes, the determination of empirical dependencies between the times of the manifestation of precursors and the magnitude of earthquakes, between linear dimensions and magnitude, the establishment of physic-mechanical mechanisms of the manifestation of earthquakes, and the development of models of earthquake preparation processes.

This article is devoted to the results of long-term geomagnetic research on the problem of forecasting strong earthquakes in Uzbekistan. Absolute proton magnetometers MPP-1, MV-01 (Russia), and G-856 (USA) have been used to measure the geomagnetic field since the 1990s (**Table 1**). The sensitivity is 0.1 nTl. The error in identifying local anomalies since the 1990s did not exceed 0.4 - 0.8 nTl.

2. Results

In Uzbekistan, anomalous variations in the geomagnetic field associated with earthquakes and other processes in the Earth's crust are investigated by stationary, repeated profile and area magnetic surveys. The research is carried out on the territories of geodynamic polygons in the epicentral zones of strong earthquakes that have occurred on a network of stationary magnetic stations (**Figure 1**). Laboratory experiments were conducted to study changes in the magnetic properties of rocks under pressure and temperature. The values of expected magnetic effects from earthquakes, etc., are theoretically estimated.

Table 1. Types of proton magnetometers used and the magnitude of errors in the allocation of local anomalies during the period of research at the landfills of Uzbekistan.

Year of research	Type of magnetometer	The magnitude of the instrument error of a single measurement, in nTl	The magnitude of the local anomaly allocation error, in nTl	Note
1968-1970 yy.	PP-001, PM-5 Polish magnetometer PMP	1.0 ÷ 2.0	2.0 ÷ 3.0	
1971-1973 yy.	M-32, MMP-203	1.0 ÷ 1.5	1.5 ÷ 2.5	
1974-1979 yy.	TMP	0.1 ÷ 0.2	0.5 ÷ 0.8	
1980-1990 yy.	TMP, MPP-1, MTP-1 M, MPP-102	0.1 ÷ 0.3 0.3 ÷ 0.5	0.5 ÷ 0.8 0.6 ÷ 1.0	
1990-present	MPP-1, MTP-1 M, MV-01	0.1 ÷ 0.3 0.1	0.5 ÷ 0.8 0.3	
2015-present	Geometrics-856 GSM-19T	0.1 0.1	0.4 - 0.6 nTl 0.2 - 0.3 nTl	

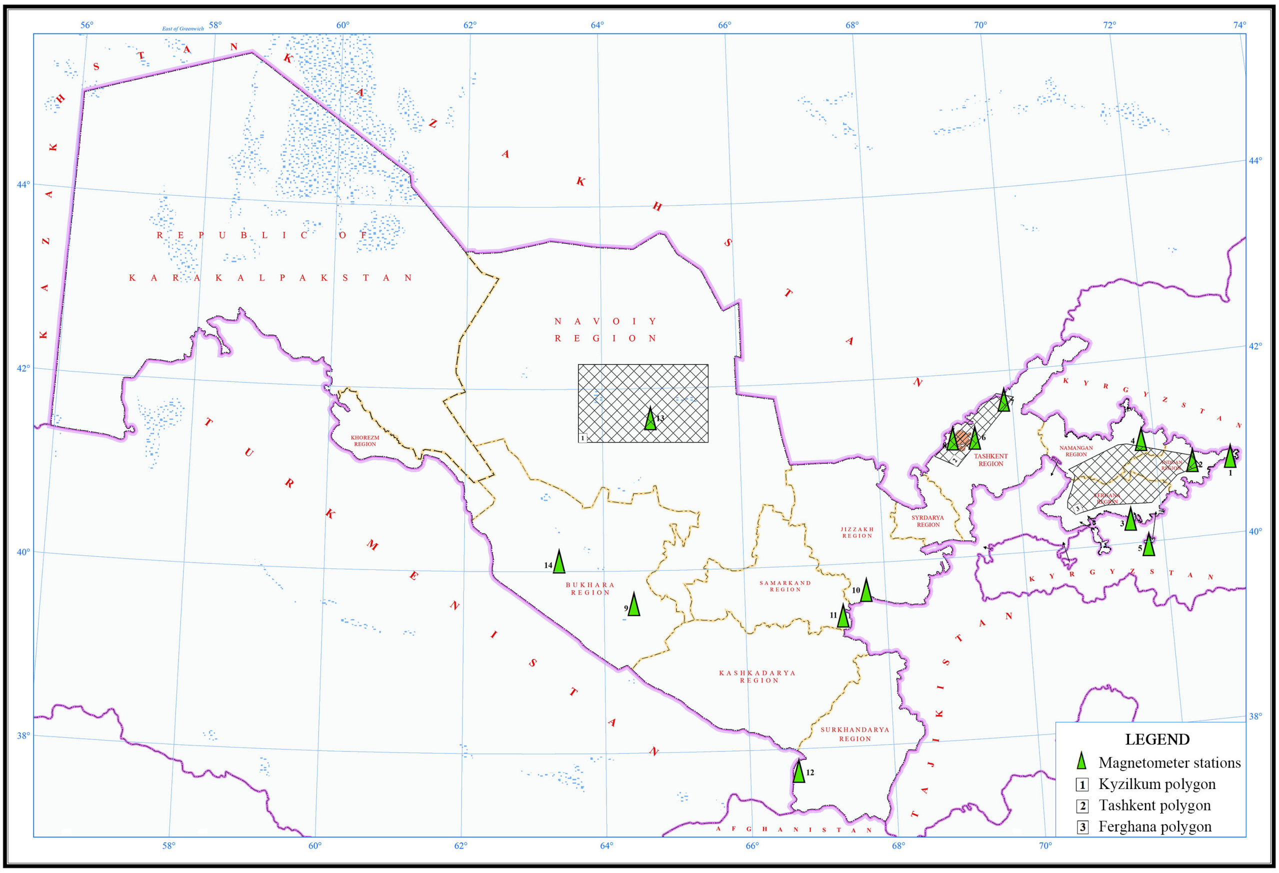

Figure 1. Layout of geodynamic polygons of Uzbekistan.

In 1968, three profiles were laid at the Tashkent Geodynamic test site together with the Russian Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN)—Western, Eastern, Secant (**Figure 2**). From 1 - 2 to 3 - 4 measurement cycles per year were carried out annually [1]. During this period, changes in the magnetic field associated with specific earthquakes were recorded at the Tashkent test site. The first was an anomalous change in the magnetic field associated with the Abaybazar earthquake on February 10, 1971 (M = 4.2) [2] [3]. The earthquake occurred in the immediate vicinity of the southwestern points of the Western Route (**Figure 2**). An abnormal change was detected at 11 points of the profile. The intensity of positive abnormal changes reached 23 nTl, and that of negative changes reached 15 nTl.

In 1972-1975, the Fergana, Kyzylkum, Charvak, and Poltoratsky polygons were organized. A network of stationary stations has been set up almost throughout the seismically active territory of Uzbekistan. Later, academic institutes of Russia joined these studies—the Institute of Earth Physics (Moscow), the Institute of Geophysics (Yekaterinburg) and the Institute of High Temperatures (Moscow). Our landfills have practically turned into international ones. In 1975-1990, measurements were carried out in the territory of Uzbekistan at 1110 ordinary points, 37 stationary stations and the Yangibazar Observatory. The length of the magnetic profiles was 7747 km. During this period, numerous anomalous changes in the magnetic field associated with earthquakes and other processes in the Earth's crust were identified [4]. This paper highlights the results of the detection of precursor anomalies in the geomagnetic field (Table 2).

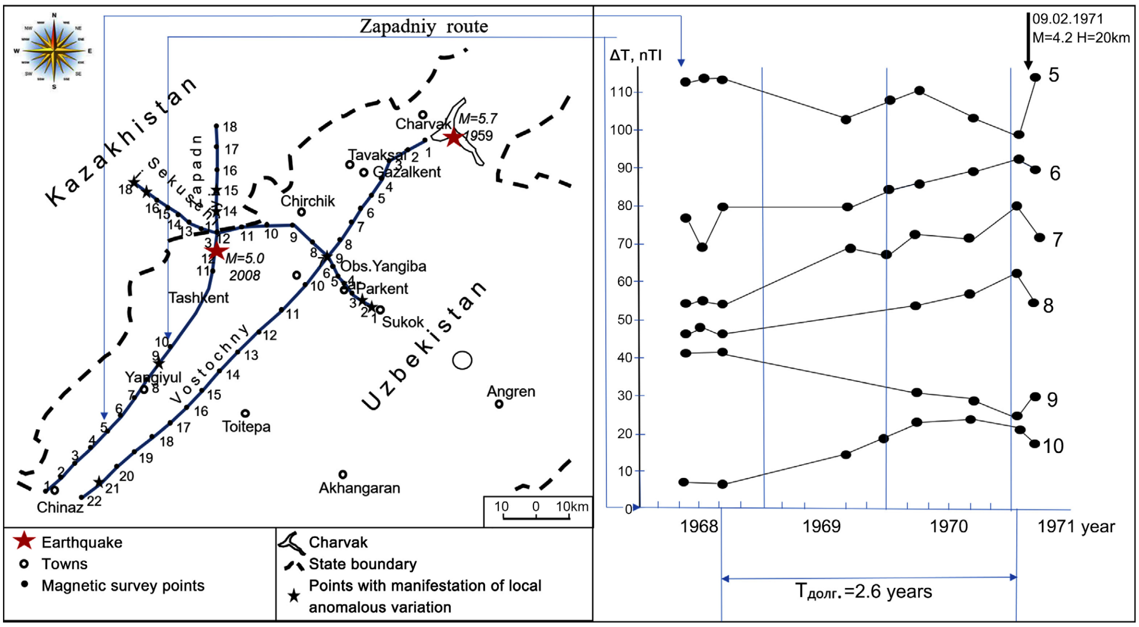

Figure 2. Layout of three geomagnetic profiles in the territory of the Tashkent geodynamic polygon. Anomalous changes in the magnetic field over time at certain points along the Western Route associated with the Abaybazar earthquake of February 9, 1971, with a magnitude of M = 4.2 (T long-term = 2.6 years).

Table 2. Geomagnetic profiles of repeated surveys.

	The name of geodynamic polygons, man-made objects and epicentral zones	Length of profiles, km	Number of geomagnetic points	Average distance between points, km
1	Tashkent polygon	400	90	4.5
2	Ferghana polygon	1800	250	7.2
3	Kyzylkum polygon	500	105	4.7
4	Epicentral zones: Gazli earthquakes IV.V.1976, III.1984.	150	25	6.0
5	Tavaksay earthquake 6.XII.1977.	8	11	0.7
6	Nazarbek earthquake11.XII.1980.	50	12	4.2
7	Chimion earthquake of 6.05.1982	60	12	5.0
8	The water area of the Charvak reservoir	86	30	2.8
9	Poltoratsk gas storage facility	10	9	1.1
10	Kokdumalak oil Field	8	4	2.0
11	Shurtan gas field	35	16	2.2
12	Pamuk-Zevardinsky Group of Structures gas field	40	51	0.8
13	Gas fields of Khauzak-Shady (Dengizkul)	100	35	2.8
14	Zones of abnormal electrical conductivity	1500	160	9.4
15	Regional profiles	3000	300	10.0
	Total	7747	1110	4.2

Many of the results obtained at the landfills of Uzbekistan are unique in the practice of studying the seismomagnetic effect, but the main result is the birth of a large team of seismologists—magnetologists in Uzbekistan and the creation of a scientific school—dynamic geophysics.

Extremely valuable is the result associated with the Tavaksay earthquake on December 6, 1977, with M = 5.3, obtained at one of the points of the Secant route at the Tashkent landfill. The measurements were started in 1968 and were repeated 3 - 4 times a year. Against the background of minor changes of an oscillatory nature, intense anomalous changes of a long-term and medium-term nature are highlighted (**Figure 3**.) From 1968 to 1975, slow long-term anomalous changes are observed, and from 1976 to the moment of the earthquake, medium-term changes are observed. This result is extremely valuable and unique. The change covers two stages of the earthquake preparation process (**Figure 3**).

Anomalous changes in the geomagnetic field at Secushchy-9 appeared in early 1975, and in 1976, its amplitude was 19 nTl, and by mid-1977, it was 18 nTl. The observation point of anomalous changes is located only 20 km to the west of the epicenter of the earthquake. Anomalous changes in the geomagnetic field, in addition to the Secushchy 9 point of the Tashkent polygon, were also detected at 7 points of repeated observations of the Charvak polygon. The anomalous changes at the points of the Charvak polygon in terms of time and form of manifestation are almost the same as the changes at the Secushchy-9 point. The Charvak polygon is located 30 - 50 km to the east of the epicenter, and the amplitude of anomalies there is less than that at section 9. This shows the correlation of geomagnetic anomalies with the processes of preparation for the Tavaksai earthquake. In this case, a short-term harbinger was not registered because stationary observations near the epicenter of the Tavaksai earthquake were not carried out in those years.

For the first time, an anomaly associated with the aftershock process of an earthquake has been identified. After the Nazarbayev earthquake on December 11 (M = 5.5), geomagnetic observations were started in the epicentral zone [5]. **Figure 4** shows the results of the research in the form of decadal and monthly graphs of changes in the magnetic field at the epicentral station "Fazylov". Histograms of the released seismic energy in the hypocentral region are also shown here for comparison. A qualitative comparison of DT and lgE shows that on art. "Fazylov", there is a slow decrease in the geomagnetic field synchronously with the weakening of the seismic regime in the hypocentral region. The rate of reduction of the field is "2 nTl/month, for the given time interval, the field decreased by 27 nTl. There is a relationship between the released seismic energy and local changes in the geomagnetic field.

For the first time in world practice, high-precision measurements of the magnetic field were performed directly above the center of the strongest Gazli earthquake on May 17, 1976 (M = 7.3) before, at the moment and after the main shock. There were no short-term abnormal changes [6]. What was new was the result of an anomalous distortion of the amplitude of the cove-like changes in

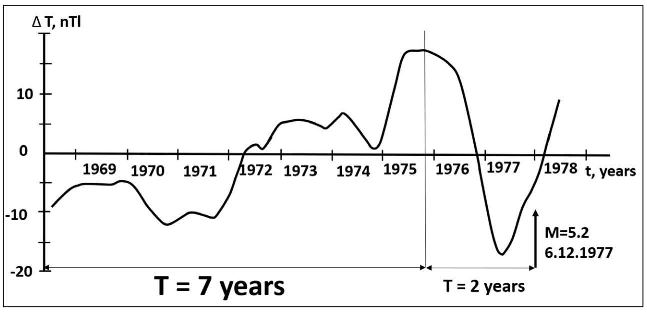

Figure 3. Anomalous variations in the magnetic field caused by the Tavaksai earthquake on December 6, 1977 (TLong-term = 7 years; medium-term = 2 years).

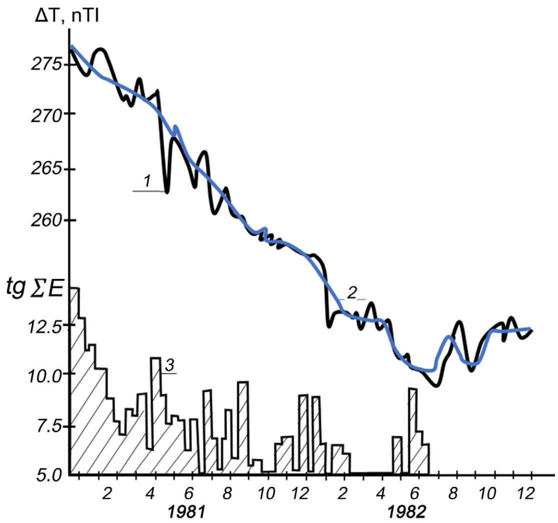

Figure 4. Anomalous changes in the geomagnetic field in the epicenter of the Nazarbayev earthquake on December 11, 1980, associated with the decline of aftershock activity. 1—decadal changes in ΔT; 2—monthly changes in ΔT; 3—released seismic energy in the hypocentral region.

the magnetic field over the epicenter of the earthquake. Compared with the indicators of other stations located from 200 to 1000 km, the amplitudes of the bays in the epicentral Gazli station were distorted to 85% - 90%. When repeated measurements were carried out a year later, the distortion was only 20% - 30%. The results were unexpected, but they showed a real picture of the changes. Distortions of bay-like variations in the epicenter of the earthquake were observed many times, and the probability of its connection with the seismic activation of the area is beyond doubt [4] [7] (**Figure 5**).

Similar distortions of bay-shaped variations were also found for the Chimion earthquake of May 6, 1982, with a magnitude of M = 5.8. **Figure 6** shows anomalous changes in the ratio of the amplitudes of bay-shaped variations at stations "Chimion" (curve 1) and "Madaniyat" (curve 2). As seen from the figure, the anomalous change in the ratio of amplitudes "Chimion"-"Yangibazar" (curve I) began almost three months before the earthquake and is associated with a distortion of the amplitude of bay-like disturbances in the area of earthquake preparation. The earthquake occurred after a sign change in the middle of a sharp increase in the value of the amplitude ratio. The change is 70% - 80% of the magnitude of the field disturbances at the Yangibazar Observatory. The value of the ratio of amplitudes "Madaniyat-Yangibazar", which is given for comparison, is almost at the same level. Notably, during the research period, there were no strong or noticeable earthquakes in the area of the Madaniyat station.

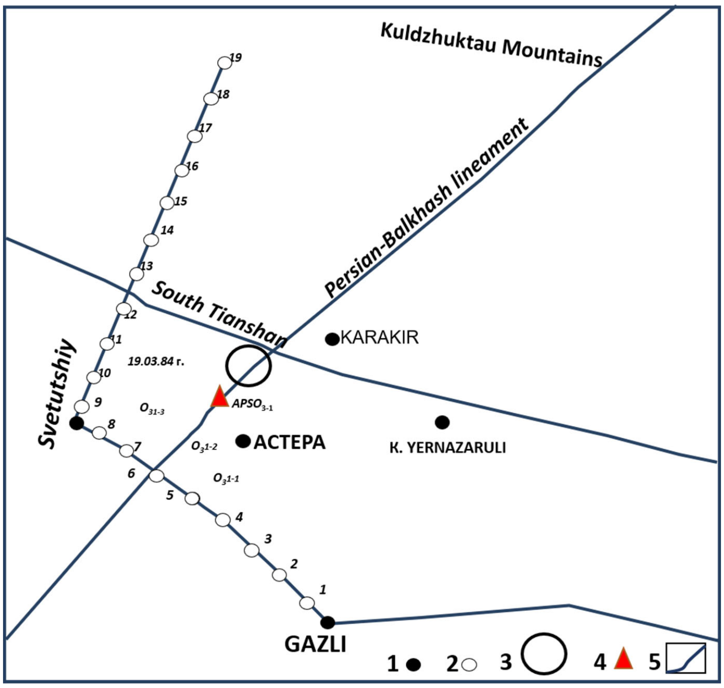

Figure 5. Tectonic diagram of the epicentral region of the Gazli earthquake (1984) and the locations of magnetic measurement points.

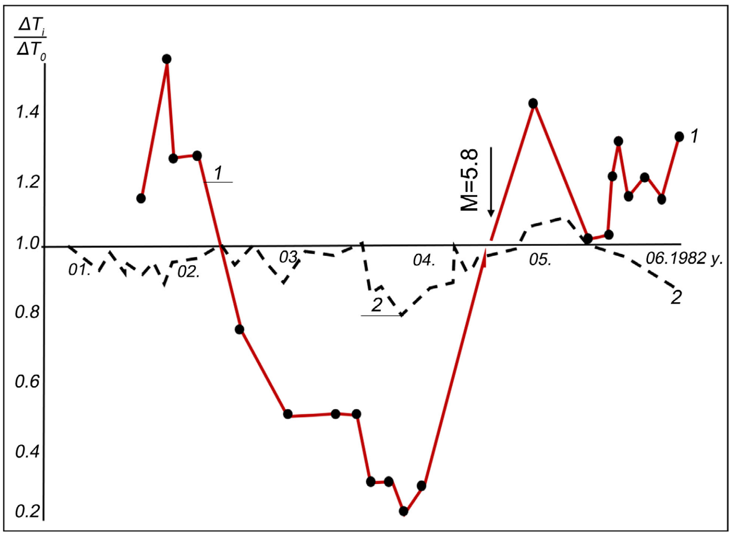

Figure 6. Anomalous changes in the ratio of the amplitudes of bay-like variations at stations "Chimion" (1) and "Madaniyat" (2) associated with the Chimion earthquake on May 6, 1982 (M = 5.8).

The results of the experiment at the East Ferghana geodynamic polygon are of exceptional interest. Here, from 1976 to 1989 (from 1979 to 1988, together with the Institute of High Temperatures), repeated areal magnetic surveys were carried out for 13 years. The research area is approximately 6.5 thousand square kilometers. Repeated areal magnetic surveys were carried out regularly with a frequency of 15 days at 40 points located evenly over the area (**Figure 7**). At the same time, continuous measurements of the geomagnetic field were carried out at the stationary stations of Tashata, Andijan, Madaniyat with a discreteness of 10 minutes. During the research period, several strong and tangible earthquakes occurred in the territory of the landfill and in the immediate vicinity of the observation points (Alay, November 2, 1978, M = 6.8; Chimion, May 6, 1982, M = 5.8; Pap, February 18, 1984, M = 5.5; Marhamat, February 19, 1968, M = 4.4, etc.

There are also numerous short-term magnetic anomalies with intensities from several to 23 nTl at the stationary stations of Tash ata, Andijan, Madaniyat and later on in the network of other stationary stations. The most interesting is the anomalous change obtained at the Andijan station at a distance of 120 - 130 km from the epicenter of the Alai earthquake on November 2, 1978, with an intensity of 23 nTl. (**Figure 7**. and here at the Andijan station (relative to the Yangibazar magnetic Observatory) on October 26-27, a magnetic anomaly appears and on October 30 reached a maximum of 23 nTl. On November 1, the anomaly began to decrease and returned to normal levels on November 2.

The earthquake was predicted based on this anomaly and the results of other complex observations six hours before the quake. This result has been published in several prestigious journals [8] [9].

Another example of the manifestation of a short-term geomagnetic harbinger is the anomalous changes detected at the Madaniyat (a), Andijan (b) and Tash ata (c) stations relative to the Yangibazar Observatory before the close Marhamat (M = 4.4) earthquake on February 19, 1986 (**Figure 8**). The epicenter of the earthquake was located in the southern part of the territory at distances of 15, 40 and 60 km from the Tash ata, Andijan and Madaniyat stations, respectively. The effect began to manifest itself 13 - 15 days before the earthquake in the form of a negative bay (**Figure 8**). The earthquake occurs closer to the end of the bay. The intensity of the anomaly at the nearby Tash ata station is 5 nTl, at remote stations—Andijan, Madaniyat—3 - 4 nTl. The anomaly was not detected at the Chimion magnetic station, located 120 km away from the epicenter to the west.

Since 1973, geomagnetic studies, unique in the world in terms of volume and duration, have been carried out on modelling earthquake preparation processes in full-scale conditions—on the territory of the Charvak reservoir (**Figure 9**). In total, more than 150 measurement cycles were carried out during the period 1973-2022. The averaged values of the geomagnetic field at 22 points of repeated observations of the polygon and seasonal changes in the volume of water in the reservoir over the months of the 40-year load-discharge cycle are shown in **Figure 10**. As seen from the figure, a local change in the geomagnetic field associated with the operation mode of the reservoir has been revealed. The amplitude of the anomalous changes ranged from 1 - 2 nTl to 4 - 6 nTl, and they are reversible, *i.e.*, With an increase in the volume of water, the value of the geomagnetic field decreases, and with a decrease, it returns to its level. A separate article will be devoted to a detailed presentation of the results at man-made facilities (underground natural gas storage facilities, large reservoirs, and exploited oil and gas fields).

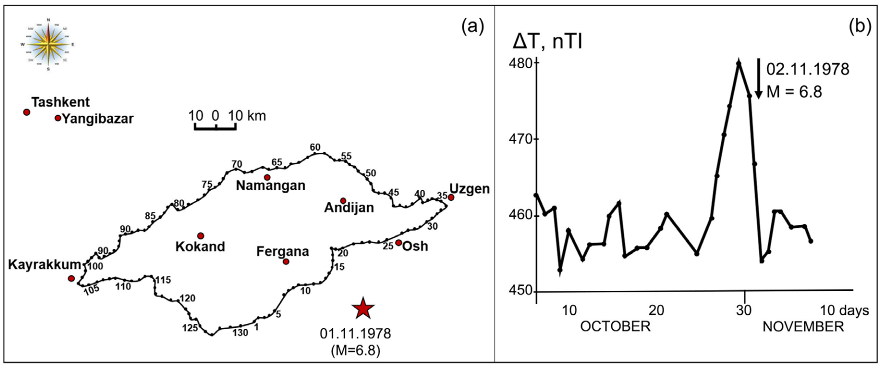

Figure 7. Layout of the geomagnetic profile in the territory of the Fergana geodynamic polygon. (a) Anomalous changes in the magnetic field at the stationary station "Andijan", (b) associated with the Alai earthquake on November 2, 1978 with a magnitude of M = 6.8, which occurred at a distance of 130 km south of the station.

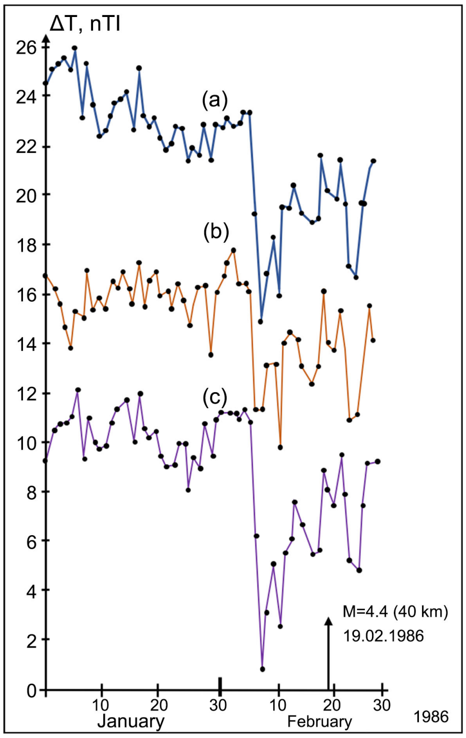

Figure 8. Anomalous changes in the magnetic field at the stationary stations of Madaniyat (a), Andijan (b) and Tashata (c) associated with the Marhamat earthquake of February 19, 1986, with a magnitude of M = 4.4.

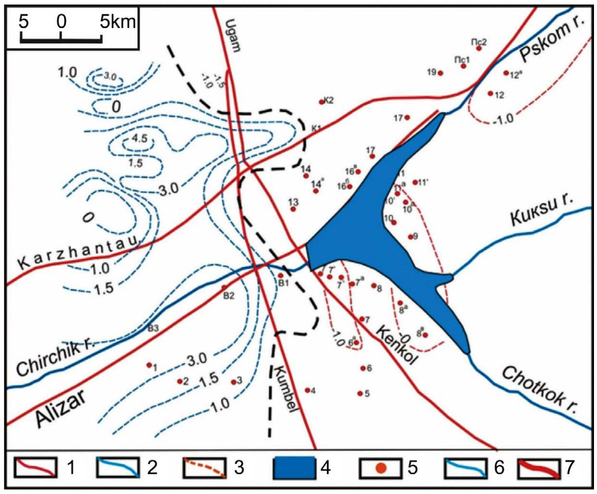

Figure 9. Schematic of the Charvak polygon (N = 41˚38'12", E = 70˚01'48"). 1 - 3—isolines of anomalous magnetic field (1—positive, 2—negative, 3—zero); 4—the contour of the reservoir, 5—geomagnetic measurement stations, 6—rivers, 7—faults.

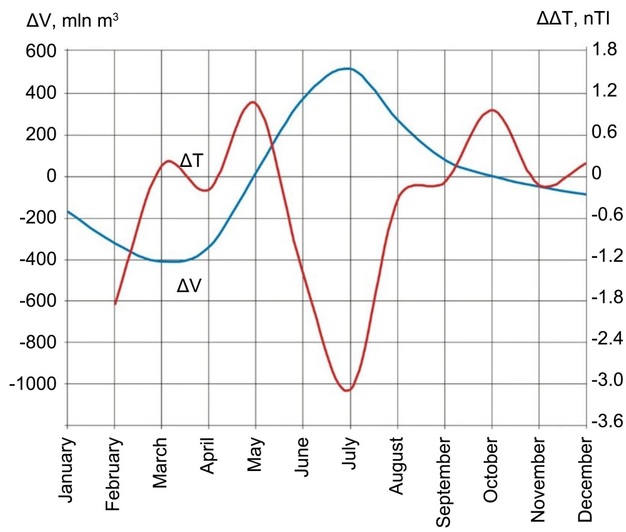

Figure 10. Anomaly versions related to seasonal changes in the water volume of the geomagnetic field in the territory of the Charvak reservoir.

Based on the analysis and generalization of the results of long-term studies of variations in the geomagnetic field, the spatial-temporal and amplitude-frequency features of the manifestation of four types of anomalous variations associated with the stages of earthquake preparation have been identified. Three types, long-term, medium-term and short-term, manifest themselves before earthquakes, and the fourth type is associated with aftershock aftershocks.

Long-term anomalous changes with characteristic times from several years to 15 - 20 years for strong earthquakes are isolated from the analysis of the results of field geomagnetic studies and data from magnetic observatories. This type of abnormal change was identified by us for the first time. Long-term magnetic precursors associated with medium-strength earthquakes were identified. The results of these studies and the data obtained at geodynamic polygons of Uzbekistan together made it possible to find a straight-line empirical relationship between the duration of the manifestation of long-term precursors and the magnitude of earthquakes, expressed by the formula T = 4 M - 14 year [11], where T is the time (duration) of the manifestation of anomalous changes in years and M is the magnitude of the earthquake.

The mid-period variations in the magnetic field are also isolated from the analysis and processing of data from repeated route and area magnetic surveys, data from a network of stationary stations and other data. Compared to long-term anomalous variations, medium-term anomalous variations are preferable. The literature contains numerous examples of the identification of anomalous changes associated with specific earthquakes. Many researchers have established dependencies between the characteristic times and the magnitude of earthquakes [8]-[15]. For Uzbekistan, the relationship between the duration of the precursors and the magnitude was LgT = 0.3 M + 0.85, where T is the duration of abnormal changes in days and M is the magnitude.

The situation is worse with the establishment of a relationship between short-term precursors and the magnitude of earthquakes. It is known that the characteristic times of the complex of short-term harbingers range from several days to several weeks and sometimes can reach up to one month. However, no dependencies have yet been established between the characteristic times of short-term precursors and the magnitude of earthquakes.

This is also the case with anomalies of the aftershock aftereffect. To date, there are no linear dependencies between the released earthquake energy and the duration of the aftershock process. However, according to numerous experimental data, the time of the aftershock process ranges from several months to 2 - 3 years, regardless of the magnitude of the earthquakes.

Based on the analysis and generalization of long-term results of studies of geomagnetic precursors of earthquakes, K.N. Abdullabekov developed a geophysical model of earthquake preparation processes [16].

3. Conclusions

Long-term geomagnetic studies have been carried out on the problem of forecasting strong earthquakes in the territory of Uzbekistan. The research was carried out on the territories of specially organized geodynamic polygons. Complex geological and geophysical (magnetometric, pulsed electromagnetic, ionospheric, seismological, hydrogeochemical, etc.) studies are organized at the landfills. Geomagnetic studies were carried out using absolute proton magnetometers with a sensitivity of 0.1 nTl.

Long-term magnetometric studies at geodynamic polygons of Uzbekistan have identified long-term, medium-term, and short-term precursors associated with the stages of earthquake preparation and variations caused by the decline in aftershock activity in the hypocentral region. Empirical relationships have been established between the duration of long-term and medium-term precursors and the magnitude of expected earthquakes. A geophysical model of earthquake preparation processes has been developed.

The results of geomagnetic studies in the territories of Uzbekistan have shown the prospects, informativeness and efficiency of this method to identify the precursors of strong earthquakes. It is proposed to organize and conduct long-term geomagnetic studies using stationary and repeated areal magnetic surveys on tectonically active zones.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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