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A Review of Variations in Magnetic and Pulsed Electromagnetic Fields for Earthquake Forecasting

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ABSTRACT

This study analyzes geomagnetic and electromagnetic anomalies recorded in seismically active regions of Uzbekistan before, during, and after significant earthquakes, including Tavaksay (1977), Nazarbek (1980), Gazli (1976), Chimion (1982), Alay (1978), and others. Based on data obtained from geodynamic test sites (Tashkent, Charvak, East Fergana), four types of geomagnetic field anomalies were identified: long-term, medium-term, short-term, and post-seismic. Our research established stable correlations between the dynamics of the geomagnetic field and the processes of seismic event preparation. It was found that precursor geomagnetic anomalies can manifest 2–3 years before an earthquake, reflecting stages of tectonic stress accumulation. The shape and amplitude of anomalies depend on the distance to the epicenter, which opens possibilities for mapping focal zones. Distortions of bay-shaped magnetic field variations are considered indicators of local physico-mechanical changes in the Earth's crust, while post-seismic deviations serve as markers of relaxation processes in the earthquake focus. The work includes an analysis of anomalous variations in magnetic and impulse electromagnetic fields identified through long-term observations and proposes empirical relationships between magnitude and time, as well as magnitude and distance. A geophysical model of earthquake preparation was developed, along with methodological recommendations for improving forecasting systems. The obtained results contribute to enhancing the effectiveness of predicting the location, timing, and strength of upcoming earthquakes and expand scientific understanding of the electromagnetic manifestations of seismicity.

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This study significantly advances the development of seismology and geophysical field monitoring by offering new approaches to early seismic hazard warning.

Keywords: Geomagnetic Anomalies; Electromagnetic Precursors; Earthquake Preparation; Aftershock Activity; Geophysical Model; Earthquake Magnitude; Seismic Forecasting; Geodynamic Polygons

1. Introduction

This article presents key findings from long-term multidisciplinary research on magnetic and impulse electromagnetic field variations associated with earthquakes and broader geodynamic processes within the Earth's crust. Understanding these variations is important because they can serve as indicators of stress accumulation, crustal deformation, and the possible onset of seismic activity. In this context, geophysical monitoring of magnetic and electromagnetic fields provides promising opportunities for investigating the physical mechanisms involved in earthquake preparation and related tectonic phenomena ^[1-5].

Systematic studies of anomalous magnetic and electromagnetic field variations linked to seismogeodynamic processes have been conducted in Uzbekistan since 1968. Over time, these investigations have developed into a comprehensive research program integrating diverse scientific approaches and methodologies. The program includes long-term field experiments performed at geodynamic test sites through repeated profile and areal magnetic surveys; targeted investigations near technogenic facilities; and field studies within the epicentral zones of major earthquakes ^[6-8].

Continuous monitoring has also been carried out through a network of stationary magnetometric and impulse electromagnetic stations located in seismically active regions. Complementary laboratory experiments have examined how rock magnetic properties respond to changing pressure and temperature conditions, while theoretical modeling and analyses of long-term geomagnetic data have further supported the research. A major result has been the development of a geophysical model describing earthquake preparation processes, offering new insights into the relationship between electromagnetic phenomena and tectonic activity and contributing to advances in earthquake forecasting and seismic hazard assessment ^[9-12].

2. Materials and Methods

This study is based on a substantial body of scientific data accumulated through decades of systematic research on magnetic and impulse electromagnetic field variations associated with seismic and geodynamic processes in Uzbekistan. Much of the material collected since 1968 had no direct analogue in global geophysical practice at the time and reflects pioneering efforts in solid Earth geophysics. The first research phase (1968–1990) resulted in numerous publications, including peer-reviewed articles and monographs, which outlined the initial theoretical framework and experimental foundations. Although the subsequent phase (1990–2025) generated extensive results, many remained dispersed across various outlets, limiting accessibility for specialists in seismogeodynamics and earthquake forecasting. The present article synthesizes these findings and highlights their relevance for understanding earthquake preparation processes ^[13-15].

A significant portion of the research benefited from collaboration with leading institutions of the former USSR, including IZMIRAN, the Institute of Earth Physics, the Institute of High Temperatures, the Geophysical Institute of the Ural Branch, and Tomsk Polytechnic Institute. Joint activities included field campaigns at geophysical test sites, methodological exchange, and co-authored publications, which strengthened the interdisciplinary scope of the work ^[16-19].

By the mid-1970s, magnetic and electromagnetic observations had expanded to a wide regional network consisting of approximately 400 temporary measurement points, 37 stationary stations, and the Yangibazar geophysical observatory. Anomalous geomagnetic variations, initially considered rare, were increasingly detected and by the early 1980s were widely recognized as typical indicators of geodynamic activity ^[20-23].

The research methodology integrated field, laboratory, and theoretical approaches. Repeated profile and areal magnetic surveys using high-precision proton magnetom-

eters enabled detection of both short-term anomalies and long-term trends. Continuous observations at stationary magnetometric stations provided essential time-series data for identifying precursor patterns. Impulse electromagnetic measurements captured transient high-frequency signals associated with rapid crustal deformation. Laboratory experiments examined the response of rock magnetic properties to pressure and temperature changes, simulating tectonic stress conditions. Theoretical modeling was used to predict the spatial and temporal evolution of magnetic anomalies, while integrated data analysis techniques were applied to correlate observed field variations with seismic events.

A particularly illustrative example of the effective-

ness of this methodology is found in the observations surrounding the Tavaksay $M = 5.2$ earthquake of December 6, 1977. Monitoring had been ongoing at points along the cross-sectional route of the Tashkent geodynamic test site since 1968, with measurements taken 3–4 times per year. This long-term data series enabled researchers to detect both long-term (1968–1975) and medium-term (1976–1977) anomalous changes in the magnetic field that preceded the seismic event. These observations are notable not only for their clarity but also for their ability to capture both early-stage tectonic stress accumulation and more immediate pre-seismic activation—providing a rare empirical record of the full cycle of earthquake preparation (**Figure 1**).

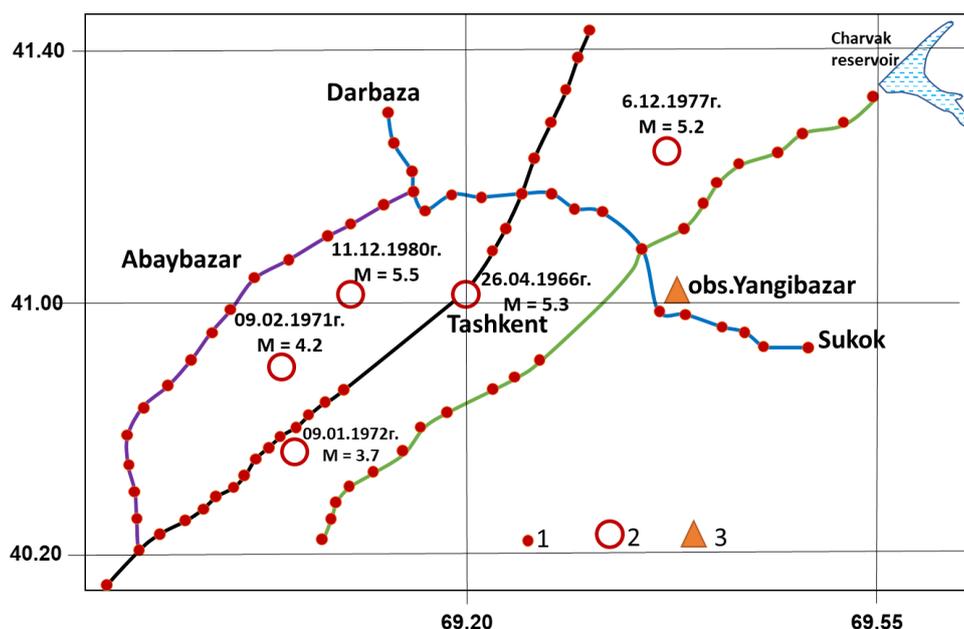


Figure 1. Diagram of magnetic field measurement points at the Tashkent geodynamic test site.

Note: 1 – points established in 1968, 1970, 1975; 2 – earthquake epicenters.

As a result of decades of rigorous data collection and methodological refinement, Uzbekistan has established a substantial and scientifically valuable archive of geomagnetic and electromagnetic observations. The empirical foundation laid by this work played a central role in the emergence of a distinct national scientific discipline—applied seismomagnetology. This field, focused on identifying and interpreting magnetic and electromagnetic precursors of earthquakes, has become a vital component of broader seismic risk assessment efforts in the region.

Over the years, this body of work has yielded hun-

dreds of scientific publications, dozens of monographs, and several registered inventions and patents. It has also led to the development of new approaches in earthquake forecasting, grounded in a deeper understanding of the physical interactions between tectonic processes and the Earth’s magnetic environment ^[22,23].

3. Results

The materials presented in this article reflect a long-term scientific effort to understand the relationship between

variations in magnetic and electromagnetic fields and seismic activity. This research direction, developed over several decades, may significantly enhance the accuracy and reliability of future earthquake prediction methods.

In the 1970s, international scientific literature featured active debates regarding the existence of anomalous magnetic field changes associated with earthquakes. Any reliably recorded anomaly was considered a major scientific event. During this period, several magnetic field disturbances were detected at the Tashkent geodynamic test site, either preceding or accompanying seismic events [24].

The first and most illustrative case was the anomalous magnetic field change linked to the Abaybazar earthquake of February 10, 1971 ($M = 4.2$). The epicenter lay near the Western observation route, where a classic dipole-type anomaly—positive field deviations in the center

and negative ones along the periphery—was recorded. Initially, measurements were taken at 11 profile points spaced 5 km apart; after the first anomaly was detected in 1969, spacing was reduced to 2–3 km for greater detail. The anomalous zone extended roughly 25 km, with maximum positive deviations of +23 nTl and negative deviations of -15 nTl. This became the first documented evidence of a direct link between seismic activity and magnetic field variations [24,25].

The success of the Tashkent site led to the establishment of additional geodynamic stations across Uzbekistan. Subsequent results confirmed stable correlations between geomagnetic anomalies and the preparatory processes of the Tavaksay earthquake of December 6, 1977 ($M = 5.2$), particularly evident in medium-term magnetic field variations at point Sekushiy-9 (Figure 2).

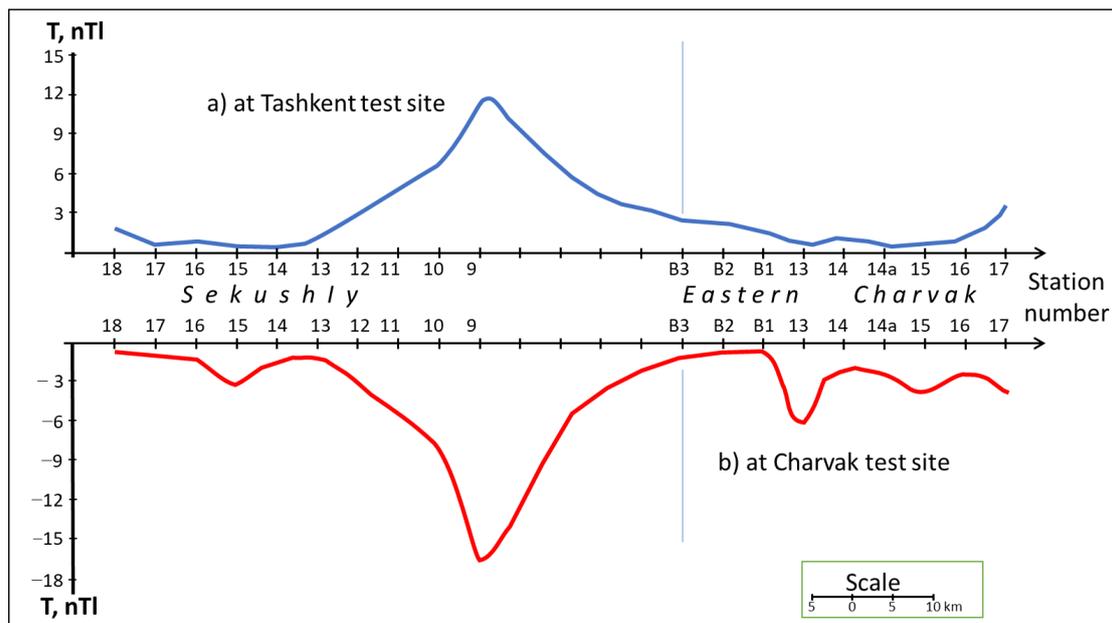


Figure 2. Anomalous variations of the magnetic field along the Darvaza–Gishtkuprik–Chirchik–Chorbog profile associated with the Tavaksay earthquake of December 6, 1977.

Anomalous geomagnetic changes at the Sekushiy-9 point began in early 1975, allowing them to be classified as medium-term precursors. The anomaly peaked in 1976 with a positive deviation of +19 nT, followed by a rapid decline to -18 nT by mid-1977, only months before the Tavaksay earthquake. This pattern supports the model of magnetization and demagnetization phases driven by stress redistribution and microfracturing within the focal zone.

Short-term precursors were not recorded due to the

absence of stationary magnetometric stations near the epicenter, highlighting the critical need for continuous, round-the-clock monitoring in seismically hazardous regions. Comparative analysis with the Charvak test site, located 30–40 km from the epicenter, revealed geomagnetic anomalies of similar form and timing at seven points, though their amplitudes were 3–4 times lower than at Sekushiy-9. This inverse relationship between anomaly amplitude and distance from the epicenter supports their seismogenic origin [14].

The resemblance in temporal characteristics and waveform shapes of anomalies across different sites—despite differing amplitudes—indicates a unified source, likely situated within the Pskem–Tashkent seismogenic zone, as proposed by Skovorodkin and Maksudova^[23]. These results confirm that geomagnetic anomalies represent credible indicators of medium-term earthquake preparation. Their spatial-temporal structure and amplitude behavior provide a solid foundation for integrating geomagnetic data into regional monitoring systems.

Overall, the findings demonstrate that such anomalies may appear 2–3 years before an earthquake, depend systematically on epicentral distance, and require long-term, high-precision observations for reliable detection. The effectiveness of geomagnetic monitoring underscores its importance for national and international earthquake forecasting programs (Figure 3).

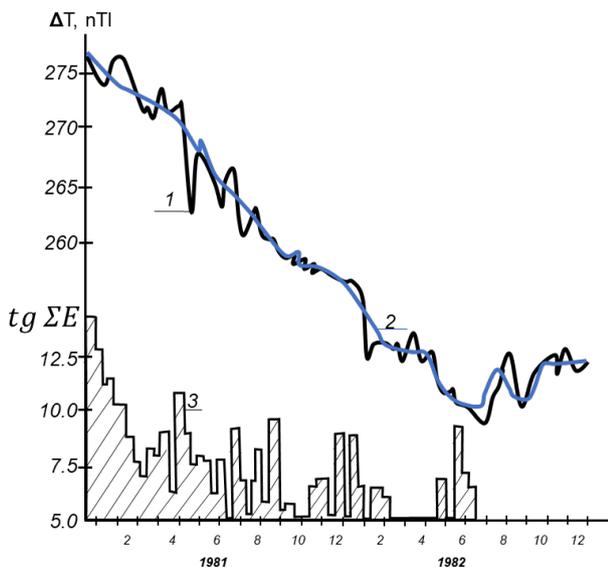


Figure 3. Anomalous changes in the geomagnetic field in the epicenter of the Nazarbek earthquake on December 11, 1980, associated with the decline of aftershock activity.

Note: 1 – decadal changes in ΔT ; 2 – monthly changes in ΔT ; 3 – Reduction of seismic energy.

Bay-type geomagnetic distortions first documented during the 1976 Gazli earthquake were subsequently detected before other seismic events, most notably the Chimion earthquake of May 6, 1982 ($M = 5.8$). For this analysis, bay-shaped geomagnetic disturbances (T) with characteristic periods of 0.5 to 2–3 h were examined. These variations, generated by ionospheric currents and

other natural electromagnetic processes, normally display similar amplitudes at all stations unless influenced by internal geological changes. The study employed amplitude ratios between stations: “Chimion,” situated near the epicenter, and “Madaniyat,” located in a stable, aseismic zone. Figure 4 illustrates these amplitude ratios: Curve 1 shows Chimion–Yangibazar, and Curve 2 the control ratio Madaniyat–Yangibazar.

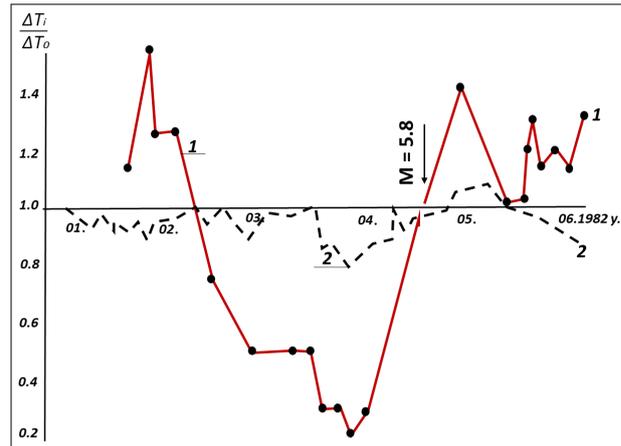


Figure 4. Anomalous changes in the amplitude ratio of bay-type variations at the “Chimion” (1) and “Madaniyat” (2) stations associated with the Chimion Earthquake of May 6, 1982 ($M = 5.8$).

Repeat measurements conducted a year later at the same observation point under identical conditions revealed that the intensity of bay-type magnetic distortions had decreased to 20–30%. This reduction confirmed their temporal correlation with the activation period of the seismogenic zone and indicated that the observed phenomenon reflected either preparatory processes or the aftermath of a major tectonic event. Such distortions of bay-shaped magnetic variations are interpreted as the result of local redistribution of electrical conductivity and stress within the Earth’s crust under the influence of external electromagnetic drivers. It is hypothesized that changes in the mechanical properties of the medium preceding fracturing can modify the propagation paths of electromagnetic waves or enhance interactions with anomalous electric currents in conductive crustal layers. Therefore, these disturbances are viewed not as direct magnetic precursors, but as secondary effects indicating variations in the physical state of the lithosphere.

No comparable distortions were recorded at other

stations, confirming their localized nature and direct association with the focal zone. This makes the effect particularly valuable for the local monitoring of active tectonic regions, as it provides a method for identifying highly stressed areas based on distortions of externally induced magnetic signals. Unique observations conducted in the epicentral area of the Gazli earthquake substantially expanded the understanding of seismomagnetic effects. They demonstrated that even in the absence of short-term magnetic precursors, anomalies in externally driven signals can serve as sensitive indicators of lithospheric activation, offering new avenues for the development of electromagnetic forecasting methods.

Anomalous changes near Chimion began in early February 1982, nearly three months before the earthquake. The amplitude ratio gradually decreased to a minimum in mid-April, followed by a sharp rise that returned to background levels at the moment of the earthquake. The shape of Curve 1 indicates a systematic deformation process occurring against the backdrop of external magnetic excitation. A key feature is the phase-shift point—where the trend reverses—occurring immediately before the earthquake, signaling a transition from stress accumulation to instability. Maximum distortions reached 70–80% of the background amplitude at Yangibazar, indicating profound changes in the physical and electromagnetic properties of the epicentral region.

Data from the Madaniyat station confirmed the local nature of the effect: Curve 2 remained stable, with only minor fluctuations synchronized with the minimum of Curve 1. The absence of significant seismic activity near Madaniyat validated its role as a reference station. These observations indicate that the amplitude changes resulted from local distortions in electromagnetic signal propagation due to stress-induced variations in conductivity, microcracking, and changes in magnetic tensor properties. Thus, the Chimion earthquake data confirmed the consistency of bay-type distortion as a sensitive seismomagnetic indicator requiring continuous stationary monitoring.

Of exceptional interest are the results from the Eastern Fergana Geodynamic Test Site, where extensive magnetic surveys were conducted every 15 days across 40 points from 1976 to 1989. Continuous monitoring at Tashata, Andijan, and Madaniyat (10–20 min intervals) allowed the identification of several regional magnetic anomalies associated with

strong events, including the Alay (1978, $M = 6.8$), Chimion (1982, $M = 5.8$), and Pap (1984, $M = 5.5$) earthquakes. Numerous short-term anomalies, ranging from a few nT to 23 nT, were also detected. One notable case was a 23 nT anomaly at the Andijan station—120–130 km from the Alay epicenter—lasting a week and enabling a successful short-term prediction made 6 h before the main shock [23]. International recognition followed, including commentary in *The Times* (January 20, 1982).

Between 1982 and 1988, 70 magnetometric forecasts were submitted to the Forecasting Commission: 43% accurate in all parameters, 37% accurate in two, and 20% inaccurate [24]. Long-term observations revealed geomagnetic changes linked not only to earthquake preparation but also to anthropogenic impacts and deep geodynamic processes. Comparative analysis of global observatory data uncovered long-period (15–25 years) anomalies, including those preceding the 1920 Gori earthquake, which began as early as 1908 [23,24].

Based on the analysis and synthesis of many years of research on geomagnetic field variations, spatial-temporal and amplitude-frequency features—and in some cases even regularities—have been identified in the manifestation of four types of anomalous variations related to the stages of earthquake preparation. Three of these types—long-period, medium-period, and short-period (or long-term, medium-term, and short-term)—occur before earthquakes, while the fourth type is associated with aftershock consequences (Figure 5).

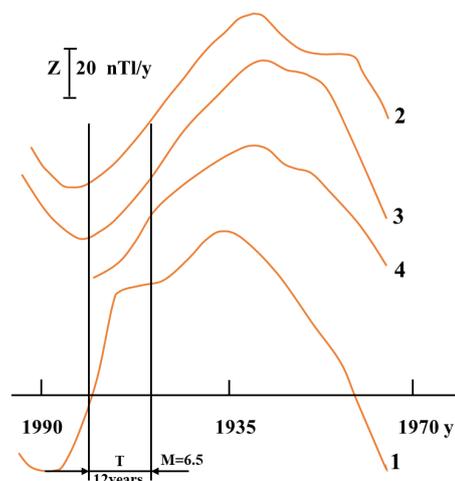


Figure 5. Features of the centennial trend of the geomagnetic field (1. Dusheti, 2. Voeykovo, 3. Vysokaya Dubrava, 4. Zaymishche).

Long-Period Anomalies: Long-period anomalous changes, with characteristic times ranging from several years for weak to moderate earthquakes, to 15–20 years for strong earthquakes, were identified through analysis of field experiments and observatory data. This type of anomaly was identified for the first time in our research. Slow anomalous variations with characteristic times of 15–25 years were also observed in: Crustal movement variations, Sea level (mareographic) measurements in Japan, Radon variations, and other geophysical fields. Long-term magnetic precursors associated with moderate earthquakes were also identified. The combined results from these studies, including data from geodynamic test sites in Uzbekistan, enabled the discovery of a linear empirical relationship between the duration of long-term precursors and the magnitude of earthquakes, expressed by the formula:

$$T = 4M - 14$$

Where: T – duration of anomalous changes in years, M – earthquake magnitude ^[23].

This result is of significant importance for the development of earthquake preparation process models. **Medium-Period Variations:** Medium-period variations of the magnetic field were also identified through analysis and processing of repeated route and areal magnetic surveys, stationary station network data, and other observations. Compared to long-term variations, medium-term anomalies are more favorable for practical use. There are numerous documented cases in scientific literature where anomalous changes were linked to specific earthquakes. Many researchers have established relationships between characteristic times and earthquake magnitude. For the conditions in Uzbekistan, the relationship between precursor duration and magnitude was determined as:

$$T = 0.59M - 0.75$$

Where: T = duration of anomalous changes in days, M = magnitude of the earthquake. This finding was also used in constructing a geophysical model of earthquake preparation processes. **Short-Term Precursors:** Establishing a relationship between short-term precursors and earthquake magnitude has proven more difficult. It is known that characteristic times for short-term precursors range from several days to a few weeks, and sometimes up to one month. However, no reliable dependencies between

short-term precursor duration and earthquake magnitude have been established so far. As an example, we present some results from the study of anomalous variations of impulsive electromagnetic radiation from the Earth's crust, which manifest several days before earthquakes. Research into this type of variation in Uzbekistan began in 1971, in collaboration with scientists from the Tomsk Polytechnic Institute, in the area of the Charvak Reservoir. The first results—anomalous changes in impulsive electromagnetic radiation at a frequency of 12 kHz, associated with a local earthquake of M = 4.0—were recorded in January 1972. From that point on, continuous observations were conducted at the Tashkent and Fergana geodynamic test sites. Over a short period, dozens of anomalous changes in impulsive electromagnetic radiation from the Earth's crust were recorded. These changes were linked to the Gazli earthquakes on May 17, 1976 (M = 7.3) (**Figure 6**), the Alay earthquake on October 2, 1978 (M = 6.8), and many other events ^[24,25].

To date, no direct correlation has been established between the decay of aftershock activity and earthquake magnitude. However, this does not have critical significance for the development of a geophysical model of earthquake preparation processes, since the time interval for short-term effects (in comparison with long-term and medium-term ones) is very short—from a few days to 2–3 weeks—and thus does not significantly affect the overall model structure. The same applies to anomalies of aftershock consequences. So far, no linear dependency has been found between earthquake energy and the duration of the aftershock process. Yet, numerous experiments have shown that aftershock duration can range from several months to 2–3 years, regardless of the earthquake's magnitude. Similar studies were conducted during the early years of the Institute of Seismology by Skovorodkin and Maksudova ^[23]. Between 1967 and 1976, they developed a five-stage model of earthquake preparation based on the results of 10 years of systematic measurements of radon content in the thermal mineral waters of the Tashkent Artesian Basin. This model was developed based on a recently discovered phenomenon—changes in the gas and chemical composition of underground mineral waters prior to earthquakes ^[23–25]. It proved to be fully competitive with other existing models at the time, such as

LNT and DD. Nevertheless, scientific efforts to refine the model were not continued by the original authors or their

successors. Proposed Four-Stage Geophysical Model of Earthquake Preparation

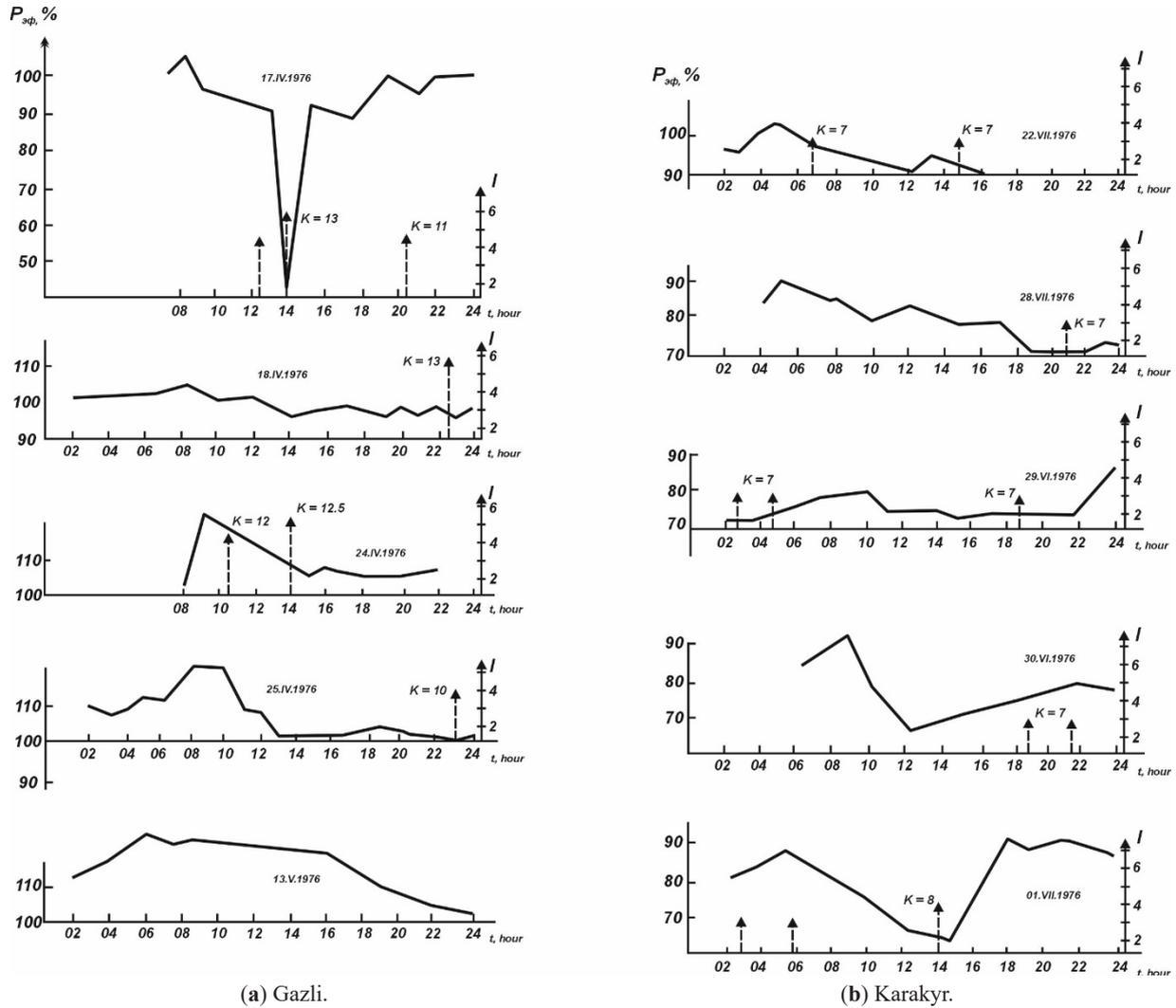


Figure 6. Graphs of daily changes in r_k at the Gazli and Karakyr stations.

Based on four types of anomalous electromagnetic field variations, identified through long-term field experiments and associated with different stages of earthquake preparation and manifestation, we have proposed a four-stage geophysical model of the earthquake preparation process (see Figure 7). The model is presented in five versions for earthquakes with magnitudes: $M = 4, 5, 6, 7,$ and 8 .

The presented graphs illustrate the temporal evolution of anomalous geophysical field variations: the x-axis represents time (years), and the y-axis shows the amplitude of these anomalies. Long-term precursor durations follow the relation $T = 4M - 14$, while medium-term precursors

are described by $T = 0.59M - 0.75$; short-term precursors last 10–15 days, and aftershock activity continues for several months. The proposed model differs significantly from the well-known models of V. I. Myachkin, Sykes, G. A. Mavlyanov, V. I. Ulomov, and I. P. Dobrovolsky. Its distinguishing features are its experimental foundation, the identification of four types of anomalous geophysical variations, and clear differentiation in both time and earthquake magnitude—factors insufficiently incorporated into earlier models due to limited datasets.

The model is primarily based on ground-based and satellite observations carried out at specialized geodynamic test sites. According to Abdullabekov K.N. [24]

and Maksudov S., Yusupov, V., and Khakimov, E.N. [25], earthquake preparation encompasses four stages. Stage I involves slow, long-term accumulation of elastic stresses lasting from months to decades. This stage is marked by piezomagnetic magnetic field changes reaching 150–250 nT over 10–15 years and variations in electrical resistivity. These long-term anomalies evolve in an oscillatory manner. Stage II is characterized by differentiation of elastic stresses: “hooks” form at block contacts, stress concentration zones develop, and magnetic and electrical field variations intensify due to piezomagnetic and piezoelectric effects.

In Stage III, stresses exceed rock strength, causing avalanche-like crack formation along tectonic structures. Short-term anomalies emerge in magnetic, pulsed electromagnetic fields, and electrical conductivity. Their duration

ranges from several hours to 2–3 weeks, and the earthquake typically occurs during the decline or sign reversal of the anomaly. Stage IV follows the main shocks, during which rapid stress redistribution occurs. Magnetic anomalies decay over months to 1–2 years, while electromagnetic pulses recover within hours or days, correlating with the aftershock sequence.

Long-term magnetometric observations in Uzbekistan have revealed distinct long-, medium-, and short-term electromagnetic precursors that reflect the mechanical and physical processes of earthquake preparation and aftershock decay. Empirical relations connecting precursor duration and earthquake magnitude were established— $T = 4M - 14$ (long-term) and $\lg T = 0.3M + 0.85$ (medium-term)—forming the analytical basis of the four-stage geophysical model.

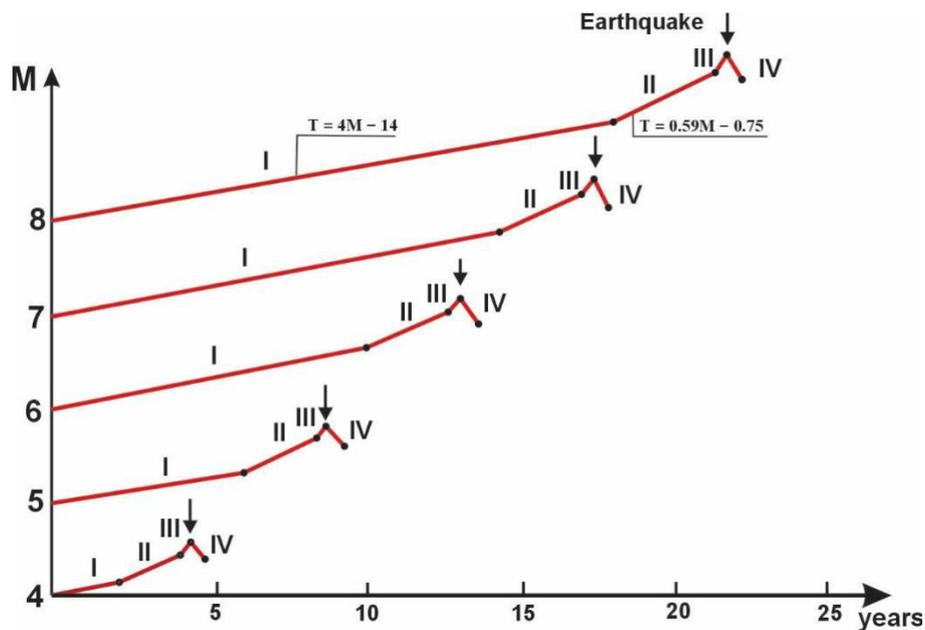


Figure 7. Geophysical model of earthquake preparation processes. The arrows show the moments of earthquakes: I, II, III – the stages of earthquake preparation; IV – the stage of the aftershock process.

4. Discussion

The results of this study significantly advance our understanding of how geomagnetic and electromagnetic field variations reflect the stages of earthquake preparation. Nearly sixty years of systematic geophysical monitoring in Uzbekistan have produced extensive empirical evidence for long-term, medium-term, and short-term precursors. These findings enabled the development of a four-stage

geophysical model of earthquake preparation, offering a refined conceptual framework that incorporates time- and magnitude-dependent characteristics—an improvement over earlier models that lacked sufficient experimental grounding.

A key outcome is the identification of stable spatial-temporal patterns in magnetic and impulsive electromagnetic anomalies that precede earthquakes of varying magnitudes. Medium-term precursors, in particular, con-

sistently appear 1–3 years before moderate and strong events with amplitudes reaching ± 20 – 25 nT and exhibiting dipole-like structures that reflect magnetization–demagnetization cycles in seismogenic zones. The empirical relations $T = 4M - 14$ (long-term) and $T = 0.59M - 0.75$ (medium-term) quantify the dependence of precursor duration on earthquake magnitude and reinforce their seismogenic origin. These relationships provide a practical basis for forecasting preparation timescales.

Short-term precursors, though frequently observed as impulsive electromagnetic anomalies in the days or weeks preceding earthquakes, remain difficult to standardize due to their brief duration and variability. Their inconsistent correlation with earthquake magnitude highlights the need for denser, continuous monitoring networks in epicentral areas. A noteworthy contribution of this research is the discovery of magnetic bay-type distortion effects—recorded during events such as the Gazli (1976) and Chimion (1982) earthquakes—which serve as indirect indicators of lithospheric activation. These localized distortions of externally induced magnetic signals reflect alterations in crustal conductivity and structure, offering an additional diagnostic tool when classic precursors are absent.

Taken together, the results validate the four-stage geophysical model and demonstrate the practical value of magnetic and electromagnetic observations for earthquake forecasting. Although challenges persist—particularly regarding short-term anomaly interpretation and the occasional absence of precursory signals—the reproducibility of long-term and medium-term anomalies confirms their significance. Integrating these findings into regional monitoring strategies can substantially enhance seismic hazard assessment and contribute to more reliable, science-based prediction systems.

5. Conclusions

This study provides a comprehensive analysis of geomagnetic and electromagnetic field variations associated with earthquake preparation, drawing on nearly six decades of geophysical research in Uzbekistan. The findings confirm the existence of distinct long-term, medium-term, and short-term precursors, each displaying characteristic

temporal and spatial patterns linked to tectonic stress accumulation and redistribution. These observations form the empirical basis for a four-stage geophysical model of earthquake preparation, validated across diverse geodynamic settings.

The model differentiates precursor types by duration and magnitude dependence, offering a refined framework for seismic hazard assessment. Empirical formulas, such as $T = 4M - 14$ for long-term and $T = 0.59M - 0.75$ for medium-term anomalies, quantify the relationship between precursor duration and earthquake magnitude, providing a practical tool for estimating preparation timescales. Medium-term anomalies, appearing 1–3 years before moderate and strong earthquakes, show reproducible patterns and spatial correlation with epicenters, highlighting their value for forecasting.

Short-term impulsive electromagnetic anomalies, observed days to weeks before earthquakes, remain inconsistent and show limited magnitude correlation, underscoring the need for denser monitoring networks and improved signal discrimination. Additionally, magnetic bay-type distortions have been identified as indirect indicators of lithospheric activation, reflecting seismogenic zone reconfiguration even when direct precursors are weak or absent.

Overall, the integration of field observations, laboratory studies, and theoretical modeling demonstrates that magnetic and electromagnetic monitoring is a reliable and actionable method for earthquake forecasting. Continued expansion of monitoring networks and interdisciplinary research will be essential to enhance predictive capability and reduce seismic risk.

Author Contributions

Conceptualization, K.N.A. and V.R.Y.; methodology, K.N.A.; software, V.R.Y.; validation, K.N.A. and V.R.Y.; formal analysis, V.R.Y.; investigation, V.R.Y.; resources, K.N.A.; data curation, V.R.Y.; writing—original draft preparation, V.R.Y.; writing—review and editing, K.N.A. and V.R.Y.; visualization, V.R.Y.; supervision, K.N.A.; project administration, K.N.A.; funding acquisition, K.N.A. Both authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study protocol was thoroughly reviewed and approved by the Scientific Council of the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan on 4 July 2025, in accordance with Resolution No. 6. This approval confirms that the research complies with all applicable ethical standards and guidelines for scientific investigations conducted by the Institute. The review process ensured that all aspects of the study, including methodology, data handling, and participant protections, meet the required institutional and national regulations.

Informed Consent Statement

Written informed consent was obtained from all participants prior to their inclusion in the study. Participants were fully informed about the purpose, procedures, potential risks, and benefits of the research. They were assured that their participation was voluntary, that they could withdraw at any time without any consequences, and that their personal data would be kept confidential and used solely for research purposes. All procedures involving human participants were conducted in accordance with ethical standards and guidelines established by the Institutional Review Board of the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable

request. Due to institutional and ethical restrictions, the datasets are not publicly available. However, anonymized portions of the data may be shared with qualified researchers upon request and with approval from the Institute of Seismology of the Academy of Sciences of the Republic of Uzbekistan. No publicly archived datasets were generated during the current study.

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Conflicts of Interest

The authors, Kakharbay Abdullabekov and Valijon Yusupov, declare that there are no conflicts of interest related to the research, authorship, or publication of this study. This research was conducted independently and objectively, based solely on scientific analysis of long-term geomagnetic and electromagnetic observations in seismically active regions of Uzbekistan. The authors affirm the following: No financial interests or personal relationships influenced the conception, execution, or interpretation of the study. The work was not funded by any third-party organization or commercial entity that could benefit from the findings. No institutional or organizational pressures affected the presentation of data or conclusions. All results and interpretations presented are based on unbiased analysis of verified geophysical data

obtained from geodynamic test sites in Tashkent, Charvak, and East Fergana. The authors have no affiliations or roles in companies, institutions, or governmental agencies that could present a potential conflict concerning this research. The authors remain committed to scientific transparency, integrity, and neutrality in all stages of their research and publication process.

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