2D AND 3D MAGNETIC FIELD MODELING USING ZOND SOFTWARE: RELATIONSHIP WITH SEISMIC ACTIVITY (CASE STUDY OF THE TASHKENT REGION)

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Abstract. In this article, 2D and 3D modeling of the magnetic field in the Tashkent region of the Republic of Uzbekistan was carried out. Based on magnetic survey methods, as well as data from six stations measuring magnetic field variations (Yangibozor, Parkent, Boyqozon, Khumson, Khumson-1, and Khumson-2), the correlation between the magnetic field and seismic activity was analyzed. The Yangibozor geophysical station was taken as a reference station, and all observations were normalized relative to this point. The results revealed a significant correlation between magnetic field anomalies and seismically active zones. In particular, anomalous areas were found to coincide with active faults and their flexure zones. This approach is currently widely used in many developed countries as an important indicator for short-term seismic forecasting and earthquake early warning systems. At the "Yangibozor Geophysical Research Observatory" laboratory located in the Tashkent region, extensive scientific research is also being conducted in several areas of geophysics aimed at early detection and prediction of earthquakes.

Keywords: magnetic survey, magnetic field, 3D modeling, earthquake prediction, geophysical studies, tectonic faults, anomalies.

Introduction

Assessment of seismic processes in advance is one of the most urgent tasks of modern geophysics [1]. In addition to classical seismic observations, systematic monitoring of variations in geophysical fields (magnetic, electromagnetic, and gravitational) serves as an important source for short-term earthquake prediction.

Magnetic anomalies are often closely related to tectonic zones and faults. They arise as a result of electromagnetic effects caused by stress accumulation in the Earth's crust [2]. Due to modern computational technologies, it is now possible to construct detailed 3D models of the magnetic field, which play a significant role in identifying seismic hazard zones [3].

This study is devoted to the 2D and 3D modeling of the magnetic field in the Tashkent region and the analysis of its relationship with seismically active areas. Within the framework of this research, during 2023–2024, magnetic field intensity

(T) measurements were carried out at designated points along survey routes in the Tashkent region using magnetic survey methods. The collected data were compared with measurements from the magnetic station located at the Yangibozor Geophysical Research Laboratory. Data processing was performed using the ZondGM2D and ZondGM3D software packages, and a 2D magnetic field map as well as a 3D model of the magnetic field for the Tashkent region were constructed.

Methods

1. Data collection

Data obtained from ground-based magnetometry and continuous monitoring stations were compiled. The Yangibozor station was taken as a reference station, and all observations were normalized relative to its daily variations.

2. Data processing

- Correction for daily variations
- Filtering of random noise
- Comparison of areas with strong anomalies with seismic events and earthquake hypocenters in the region

3. Interpolation and 3D modeling

- Based on Kriging and inverse distance weighting (IDW) methods, the data were processed in ZondGM2D software to generate a magnetic field map of the region
- A 3D model was constructed using ZondGM3D based on the same methods
- The identified anomaly zones were compared with tectonic faults and earthquake epicentral zones

Results

The results of the study showed that magnetic anomalies were observed in certain zones of the Tashkent region. Analysis of data from recent years (specifically 2023–2024) indicated that approximately 80–95% of the earthquakes recorded in the region occurred within these zones, demonstrating a strong correlation with seismically active areas.

Similar patterns were previously observed: before the earthquakes of 2013 (Tuyabog‘iz, Marjonbuloq) and 2019, significant magnetic anomalies were recorded in the data from the Yangibozor station [1].

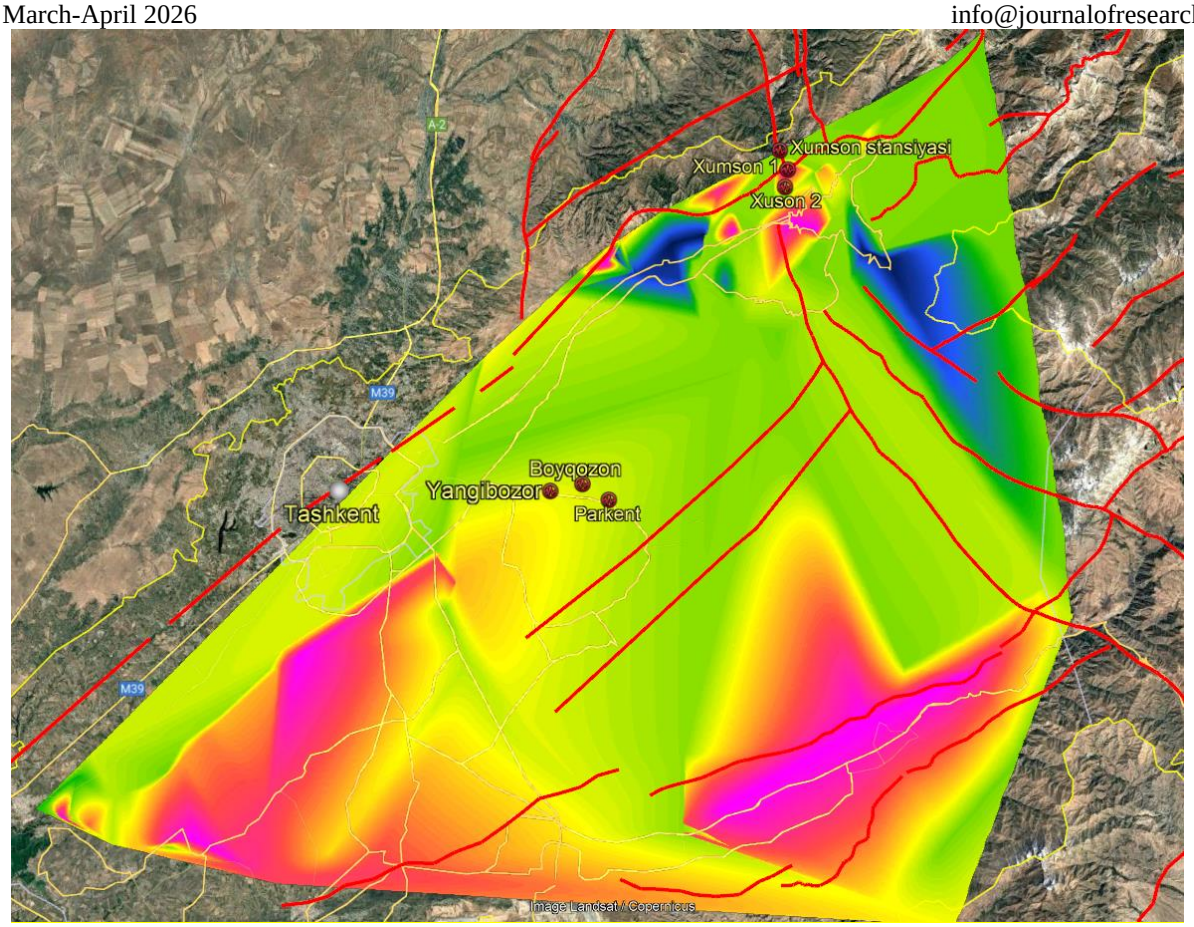


Fig. 1. Interpolation of the magnetic field anomaly map of the Tashkent region with the map of active tectonic faults [6] (for 2023).

The research results were compared through interpolation with the “Map of active tectonic faults passing through the Tashkent region” [6]. The obtained results indicate that the anomalous zones identified using 2D and 3D models of the magnetic field in the Tashkent region are closely related to geological structure and tectonic activity (Fig. 1).

The results of 2D modeling revealed mainly the directional and linear characteristics of magnetic anomalies, allowing the identification of their relationship with tectonic structures. In particular, the map compiled for 2023 shows that areas with sharp changes in magnetic gradients correspond to seismically active zones (Fig. 2). This suggests that local variations in the magnetic field may be associated with the accumulation and redistribution of tectonic stress.

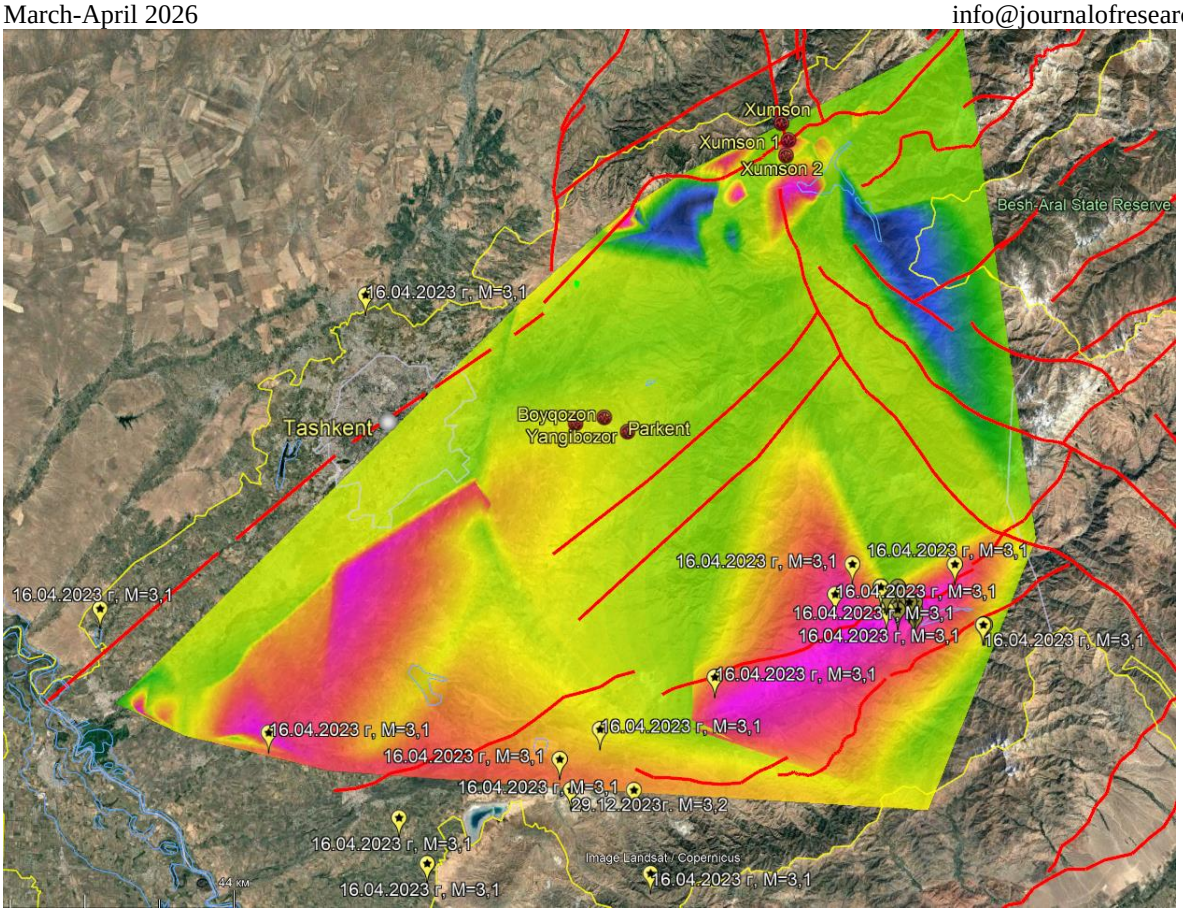


Fig. 2. Interpolation of the magnetic anomaly map with earthquake epicenters (2023).

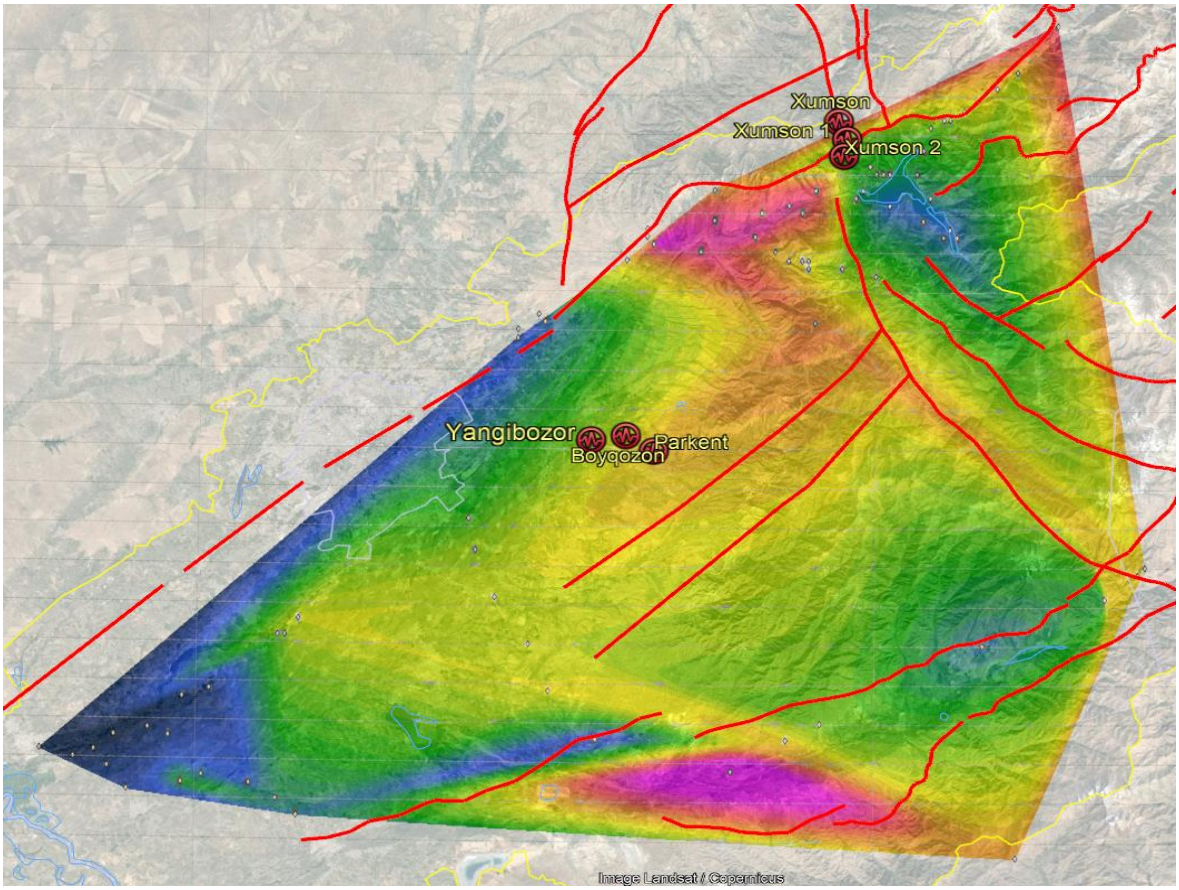


Fig. 3. Interpolation of the magnetic field map of the Tashkent region with the map of active tectonic faults (for 2024).

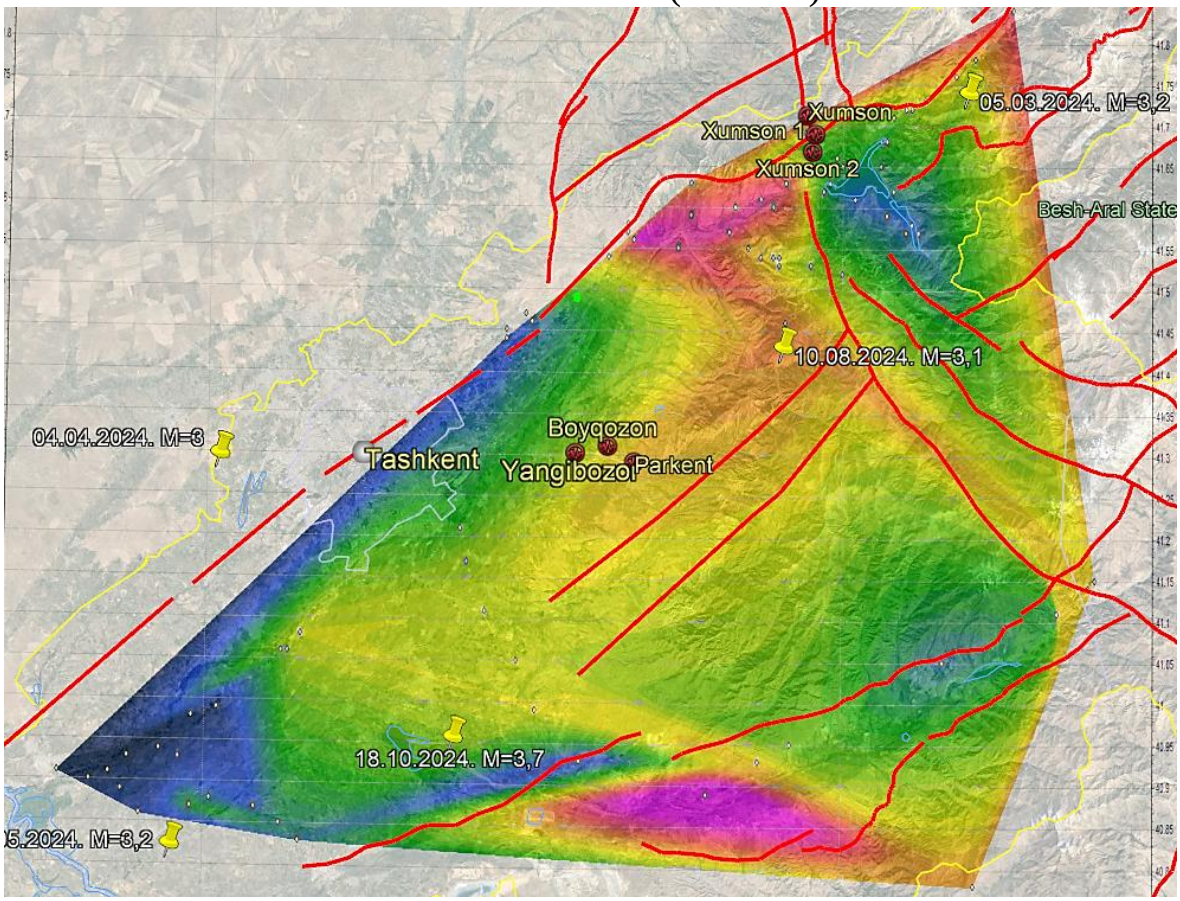


Fig. 4. Interpolation of the magnetic anomaly map with earthquake epicenters (2024).

The spatial distribution of magnetic anomalies, in some cases, was found to correspond to deep geological structures, including faults, block structures, and tectonic contact zones. This indicates that variations in the magnetic field can reflect geodynamic processes occurring within the Earth's interior (Fig. 4).

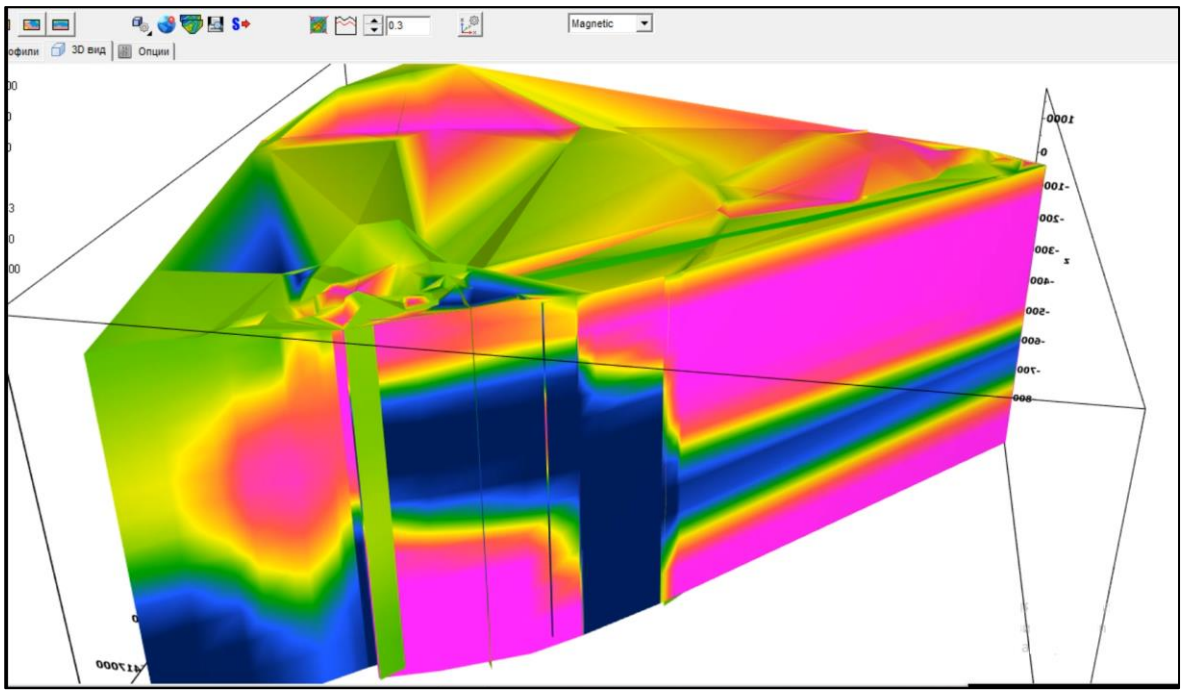
Discussion

The obtained results demonstrate the high efficiency of magnetic field measurements and magnetic survey methods in geophysical and seismological studies [4]. Magnetic anomalies show a strong correlation with tectonic faults, confirming that these faults represent seismic hazard zones [2].

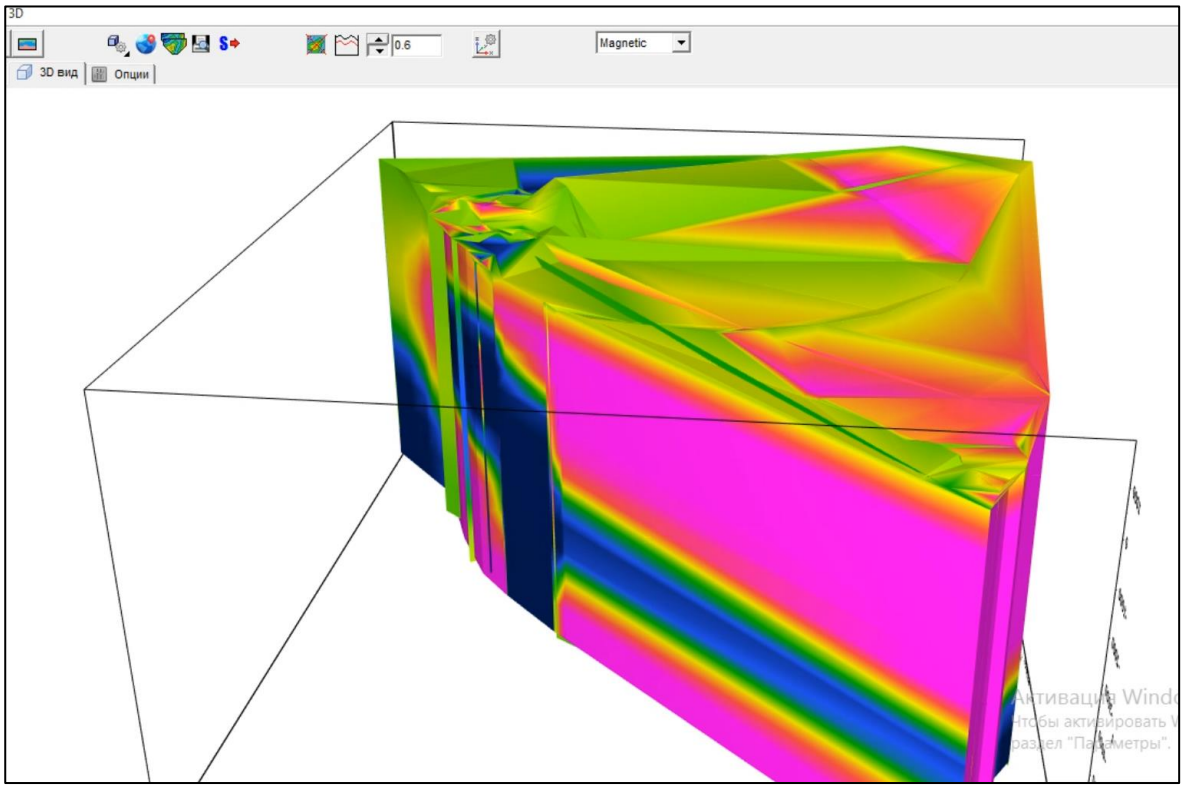
In addition, short-term variations in the magnetic field can be considered as electromagnetic precursors of earthquakes [1], [5]. It is suggested that the integrated application of magnetic surveys and seismic monitoring in the Tashkent region can significantly improve the reliability of short-term earthquake prediction.

3D modeling made it possible to analyze the depth-wise development of magnetic anomalies and provided additional information about their subsurface sources. The intensification or attenuation of certain anomalies at specific depth

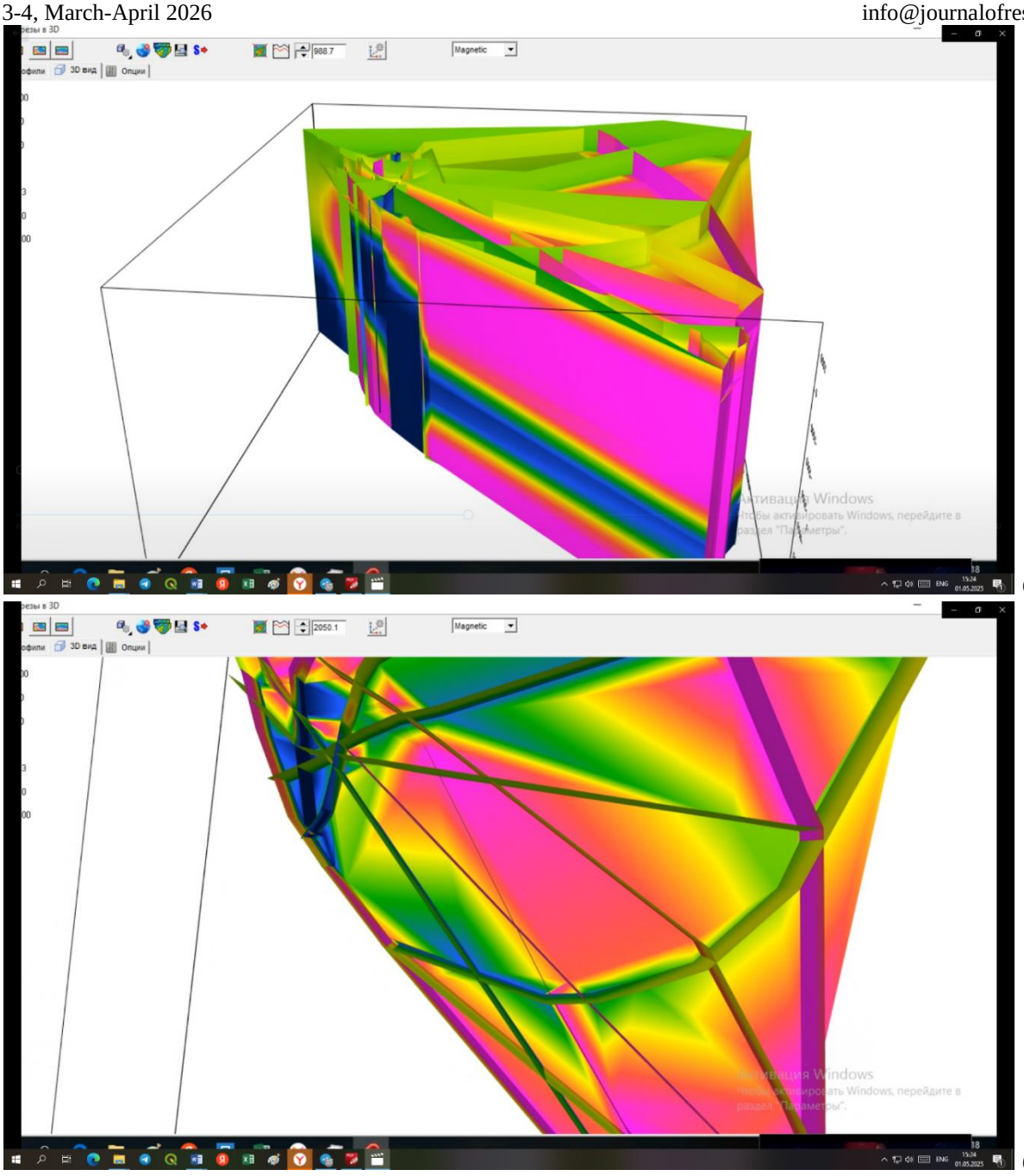
intervals may be associated with heterogeneous lithospheric structures, variations in magnetic properties, and fluid migration processes. These factors play an important role in understanding geophysical changes that may occur prior to seismic events.



a



b



c

d

Fig. 5. 3D visualization of the magnetic field of the Tashkent region (a, b, c, d) from different perspectives.

Conclusion

The mapping and 3D modeling of magnetic field anomalies in the Tashkent region were carried out based on data obtained using magnetic survey methods. The Yangibozor station was taken as a reference station, and the anomalies were analyzed in relation to seismically active zones. The results indicate that a significant proportion of the observed magnetic field anomalies in the Tashkent region correspond to active fault zones. When combined with seismological observations, these anomalies can serve as an important indicator for short-term earthquake prediction.

In general, the 2D and 3D modeling of the magnetic field in the Tashkent region has proven to be an effective approach for assessing the regional geodynamic state, identifying tectonic structures, and revealing geophysical patterns potentially associated with earthquakes. Comprehensive analysis of magnetic data can provide a valuable scientific basis for future assessment of regional seismic hazards, identification of active fault zones, and improvement of geophysical monitoring systems.

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