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Analysis of the Seismotectonic Condition of the Karjantau and North Fergana Fault Zones Based on GNSS Data and Earthquake Focal Mechanisms

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Abstract

This article assesses the current seismotectonic state of the Karjantau and North Fergana fault zones, based on GNSS observations and a comprehensive analysis of earthquake focal mechanisms. The study analyzed the results of horizontal movement velocities identified at GNSS stations located along the Chirchik, Xumsan, Chodak, and Gova profiles, as well as the mechanisms of earthquakes recorded in the Tashkent and Namangan regions. The results obtained showed the existence of relative movements of tectonic blocks separated by active faults and their different directions. Analysis of earthquake focus mechanisms showed the predominance of strike-slip, reverse, and oblique-slip types of deformation. Results of GNSS data and focal mechanisms are relatively consistent, confirming the formation of a complex transpressive deformation regime in the study area.

Keywords

GNSS, Focal Mechanisms, Seismotectonics, Modern Movements, Deformation, Seismic Activity

1. Introduction

Central Asia is one of the most seismotectonically active zones of the Alpine-Himalayan collision zone, whose modern geodynamic evolution is directly linked to the ongoing collision of the Indian and Eurasian lithospheric plates. This process leads to the formation of complex stress fields in the Earth's crust, the relative displacement of tectonic blocks, and the development of an active fault system, resulting in the region's formation as a dynamic geosystem with high seismic activity (Rustamovich et al., 2021).

The eastern part of Uzbekistan, particularly the Western Tien Shan and the Fergana Valley, is one of the zones of intensive development of modern tectonic deformations. In this region, the Karjantau and North Fergana faults play an important role in the redistribution of the regional stress field, inter-block relative movements, and the accumulation of seismic energy (Shukurov, 2018).

GNSS and InSAR technologies are currently considered the most effective geodetic-geophysical methods for studying modern crustal deformations. The theoretical foundations and practical applications of GNSS systems were developed by J. J. Spilker Jr. et al., who laid the foundation for the development of global satellite navigation (Spilker Jr. et al., 1996). High-precision GNSS data processing and geodynamic monitoring methods are based on the GAMIT/GLOBK software package developed by T. A. Herring et al. and have been widely developed in recent years (Herring et al., 2018).

The theoretical foundations of GNSS observations, the Precise Point Position (PPP) method, and its application in geodynamic research were thoroughly studied by G. Blewitt. Important scientific results in the development of multisystem GNSS technologies and the improvement of their accuracy have been achieved by O. Montenbruck and P. Steigenberger (Blewitt, 1997). The capabilities for real-time determination of deformations occurring during earthquakes have been improved by Li et al. (2015).

The possibilities of InSAR technology for monitoring Earth surface deformations have been extensively covered by D. Massonnet, K. L. Feigl, and R. F. Hanssen (Massonnet & Feigl, 1998; Hanssen, 2001). Currently, the comprehensive analysis of GNSS and InSAR data is considered one of the most promising approaches for identifying tectonic deformations, mapping active faults, and assessing seismic risk (Li et al., 2015; Hanssen, 2001). The construction and analysis of earthquake focus mechanisms is one of the fundamental methods for studying the physical nature of earthquakes occurring in the Earth's crust and the conditions of their formation. These mechanisms allow for the determination of the kinematic and dynamic characteristics of tectonic processes by analyzing the relationship between displacement vectors and stress tensors occurring in the earthquake focus. As a result, the deformation regime in the Earth's crust is compressed (reverse faulting), stretched (normal faulting), and laterally displaced (strike-slip faulting) and their combined forms (oblique-slip faulting) are clearly distinguished.

At the same time, an integrated analysis of the mechanisms of earthquake foci with deformation fields based on GNSS in the Karjantau and North Fergana fault zones has not yet been sufficiently carried out. This limits the complete and comprehensive assessment of the modern seismotectonic state of the territory. From this perspective, the primary objective of this study is to evaluate modern geodynamic processes in the Karjantau and North Fergana fault zones based on GNSS observations and a comprehensive analysis of earthquake focus mechanisms. The results serve to determine the seismotectonic evolution of the region and to assess the dynamics of movement and the stress-strain state of active tectonic structures.

Furthermore, within the framework of this study, work was conducted based on the works of foreign and domestic scientists conducting research. Among them, according to the stress tensor inversion methodology proposed by Gephart and Forsyth (1984), the predominance of inclined-shift and inverse-shift mechanisms indicates the formation of a transpressive stress regime in active tectonic zones. The mechanisms identified in the study area also indicate the joint development of regional compression and lateral displacement processes. Research conducted by Zoback (1992) in various continental regions has shown the accumulation of deformations and the formation of stress fields along large faults. The distribution of earthquake focus mechanisms indicates that the Earth's crust is still actively moving around the Karjantau, Kenkol-Pap-Chimion, and North Fergana faults. Methods for reconstructing the stress field developed by Angelier (1990) and Delvaux and Sperner (2003) have shown that compression, displacement, and local elongation processes can occur together in different tectonic media. The tensile components observed in the mechanisms of certain earthquake foci in the study area also indicate a complex and multiphase nature of the geodynamic regime.

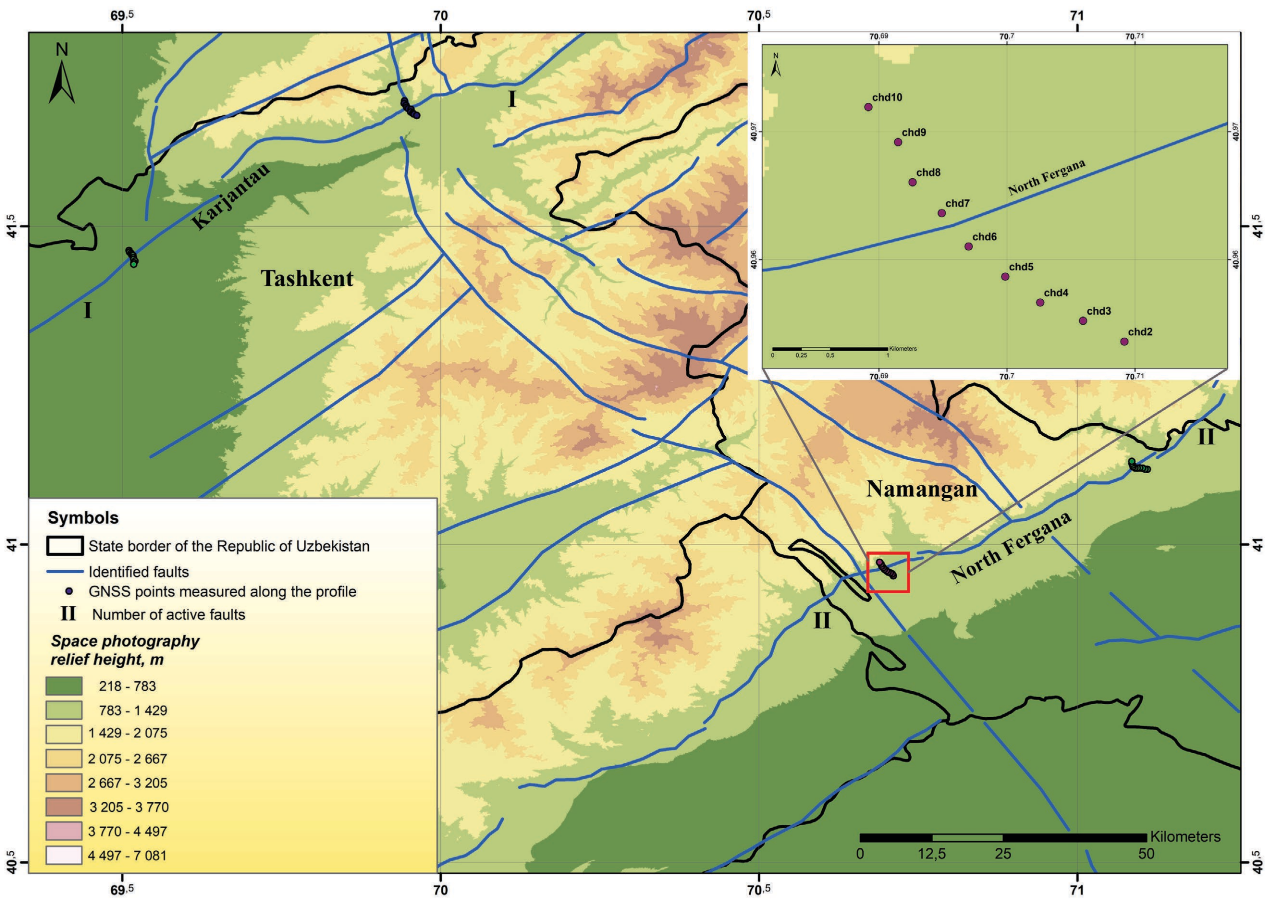
2. Materials and Methods

This study was carried out to evaluate the present-day geodynamic regime and deformation characteristics of the active Karjantau and North Fergana tectonic fault zones located within the Tashkent and Namangan regions of Uzbekistan. Particular attention was given to identifying the spatial distribution and intensity of contemporary crustal movements, assessing the kinematic behavior of the fault systems, and determining their relationship with regional seismic activity. To achieve these objectives, an integrated geodynamic approach was applied, combining high-precision geodetic observations with seismological investigations. The primary dataset consisted of repeated GNSS measurements, which provided reliable information on crustal displacement rates and directions, while earthquake focal mechanism solutions were used to characterize the prevailing stress field and fault movement patterns within the study area. The joint interpretation of these datasets made it possible to obtain a comprehensive understanding of the current tectonic activity and deformation processes occurring along the investigated fault zones.

The presented spatial coordinates of the benchmarks were used as initial data to determine modern horizontal movements and subsequently analyze the geodynamic activity of the studied fault zones. The coordinates of the points were determined based on the results of processing static GNSS observations in the GAMIT-GLOBK program within the ITRF2020 international coordinate system. During data processing, the permanent reference GNSS station TASH (Tashkent) was used as a local stationary support point.

As part of the research program, a dedicated geodetic monitoring network was established across the Karjantau and North Fergana fault systems. Six GNSS observation profiles were designed and deployed to cross the main structural segments of the faults and capture their deformation characteristics with high spatial resolution. Along these profiles, a total of 60 permanent soil marks were installed to serve as reference points for repeated geodetic surveys and long-term monitoring.

Of the total marks, 30 were positioned within the Karjantau fault zone and the remaining 30 were distributed across the North Fergana fault zone (Figure 1). The mark locations were selected to ensure adequate coverage of both the fault cores and adjacent tectonic blocks, thereby enabling the detection of differential crustal movements and the assessment of fault-related deformation patterns (Shukurov et al., 2026). This observation network forms the basis for evaluating the contemporary geodynamic activity of the study area and for quantifying the rates and directions of tectonic displacement associated with the active fault systems.



Note: I—Karjantau fault, II—North Fergana fault.

Figure 1. GNSS soil marks located in the Karjantau and North Fergana fault zones (images need to be processed, conventional symbols are unclear, and profile points should be indicated as separate footnotes).

In the Tashkent region, GNSS ground stations were established along the Khumsan, Tavaksay, and Chirchiq profiles, which perpendicularly intersect the Karzhantau tectonic fault.

In the Namangan region, GNSS ground stations were established along three profiles: Chadak, Charkesar, and Gova, which perpendicularly intersect the active tectonic zone of the North Fergana Fault. In total, six GNSS profiles were created within the studied fault zones, including 60 soil benchmarks. However, this article presents the results of only the four most representative profiles (Khumsan, Chirchiq, Chadak, and Gova), which intersect the main sections of the Karzhantau and North Fergana faults. Data from the remaining two profiles are not included in this work, as the formation of observed horizontal movement vectors is significantly influenced by adjacent tectonic disturbances, which requires additional analysis and is the subject of further research. The average distance between all GNSS ground benchmarks installed along the profiles is 300 - 400 m. This distance was chosen taking into account the terrain, geological structure, and natural conditions of the area. (Shukurov et al., 2026).

The first cycle of GNSS observations was conducted in static mode using the differential phase measurement method in September 2025. Measurements were carried out sequentially on the studied profiles: Chodak—uring DOY 260 - 262 (September 17-19), Gova—DOY 264 - 266 (September 21-23), Khumsan—DOY 266 - 268 (September 23-25), and Chirchiq—DOY 268 - 270 (September 25-27). On each GNSS benchmark, continuous static observations were conducted for 36 - 40 hours, which allowed for obtaining three-day averaged data for each point. It should be noted that repeated observation cycles were not conducted at the time of the article's preparation; therefore, all presented results are based on data from the first measurement cycle.

During the deployment of GNSS stations, special attention was paid to ensuring the long-term stability of observations. The marks were installed in areas with a low risk of mudflows, floods and landslides, at a sufficient distance from highways, power lines and other engineering structures. Furthermore, the selection of locations far from mountain slopes and settlements ensured the protection of reps from the influence of external factors.

Ground marks were concreted by installing a temporary plastic pipe in the center of a pre-prepared pit measuring 40 × 30 × 30 cm. After the concrete hardened, the temporary plastic pipe was removed, the formed cavity was filled with a special adhesive mixture, and the GNSS reference mark was fixed in a vertical position. The first cycle of GNSS observations was conducted in static mode using the differential phase measurement method. Observations were conducted at each station for 36 - 40 hours. During the measurement, the GNSS receiver was installed on the reference mark using a special rod, which eliminated the need to use a tripod and increased the efficiency of the measurement process (Shukurov et al., 2026).

Furthermore, the study analyzed earthquake focus mechanisms (focal mechanisms) to determine the modern seismotectonic state of Tashkent and the Tashkent region. To this end, torque tensor solutions and focal mechanism data for earthquakes recorded in the region were collected from international and regional seismological catalogs. For the selected earthquakes, the orientation of the nodal planes, the type of displacement, and the parameters of the main stress axes (P—compression, T—tension, and B—intermediate axis) were studied.

Earthquake focal mechanism solutions used in this study were retrieved from the Global Centroid Moment Tensor (Global CMT) catalog, an internationally recognized database providing standardized moment tensor solutions for moderate and large earthquakes. The strike, dip, and rake parameters derived from the catalog were employed to generate focal mechanism diagrams and to evaluate the deformation regime, fault kinematics, and the orientation of the regional stress field associated with the Karzhantau and North Fergana active fault zones.

In the process of analyzing focal mechanisms, "beach-ball" diagrams depicted in stereographic projection were constructed for each phenomenon, and their geometric properties were interpreted. Depending on the nature of the displacement, mechanisms are divided into groups: lateral displacement, reverse displacement, normal displacement, and inclined displacement. This classification allowed for the determination of spatial changes in the deformation regime and the assessment of the kinematic properties of active tectonic faults. The selected earthquake events and their corresponding source parameters for the focal mechanism analysis are presented in this table (Table 1).

Table 1. A table of selected earthquake events and their corresponding sources for the focal mechanism analysis.

N°	Year	H	Magn	Lon	Lat	Depth	STR_1	DIP_1	SLP_1	STR_2	DIP_2	SLP_2
1	11.12.1980	14:35	5.3	69.05	41.33	10	56	86	126	150	37	5
2	30.12.1980	1:29	4.8	69.11	41.31	10	256	88	62	162	28	175
3	25.04.1966	23:22	5.1	69.3	41.3	8	5	40	165	106	81	50
4	06.12.1977	10:53	5.2	69.7	41.6	15	14	84	98	138	10	34
5	06.12.1977	10:53	5.2	69.7	41.6	15	227	87	125	322	36	5
6	26.03.1987	11:56	5.1	69.84	41.69	20.2	37	18	2	309	89	107
7	26.03.1987	11:56	5	69.95	41.81	20	37	18	2	309	89	107
8	27.04.1985	8:21	4.6	71.12	41.2	5	72	90	117	164	28	2
9	17.02.1984	23:06	4.8	71.06	40.93	10	268	78	65	153	27	152
10	16.02.1984	0:19	4.8	71.1	40.93	15	230	84	119	325	30	7
11	17.02.1984	23:07	4.9	71.08	40.86	15	36	80	41	298	49	167
12	27.04.1985	4:14	5	71.12	40.89	10	56	86	90	234	6	88
13	17.02.1984	23:26	5.6	71.16	40.85	10	214	85	65	115	25	169

Geographical coordinates of focal mechanisms were placed in the GIS environment and analyzed in integration with data from active tectonic faults and GNSS observation stations. As a result, the spatial distribution of mechanisms and their relationship with tectonic structures were evaluated. Separately, the mechanisms of earthquakes observed at the intersection of the Karjantau fault, the North Fergana flexure-fault zone, the Kenkol-Pap-Chimion fault zone, and the North Fergana fault zone were considered.

To determine the modern geodynamic regime of the area, the directions of the compression and tension axes obtained from the mechanisms of the earthquake foci were statistically summarized. The orientation of the principal stress axes was used to determine the direction of the regional tectonic stress field. The results obtained were compared with modern horizontal displacement vectors determined on the basis of GNSS observations, and the current state of deformation processes in the Earth's crust was assessed.

Based on a comprehensive analysis of focal mechanisms, the geodynamic regimes prevailing in the area, the kinematic characteristics of active faults, and the patterns of tectonic stress distribution were determined, and the seismotectonic development characteristics of the study area were evaluated.

2.1. GNSS Technology and Data Processing

GNSS is a global satellite navigation system that allows for the determination of spatial coordinates and precise time parameters of any point on the Earth's surface. High-precision geodetic data is obtained through this system, and the spatial position of the territories is continuously monitored.

As a result of GNSS observations, first of all, three-dimensional geocentric coordinates are determined—geographical latitude, geographical longitude and absolute altitude. Accurate time values are also recorded according to the International Coordinated Time Scale (UTC—Universal Time Coordinated). These two parameters are crucial for high-precision analysis of modern movements of the Earth's crust (Shukurov, 2018).

Scientific processing of GNSS data was carried out using the GAMIT-GLOBK software package. This package was developed by scientists from the Massachusetts Institute of Technology and runs on Linux/Unix operating systems (Herring et al., 2018). The program is capable of operating in semi-automated mode, optimizing the step-by-step processing of large volumes of observation data.

Table 2. Horizontal velocity field of geodetic marks along the Chirchik, Khumson, Chodak, and Gova profiles across the Karjantau and North Fergana active tectonic fault zones.

GNSS point names	Values of horizontal movement along the X-axis, mm	Values of horizontal movement along the Y-axis, mm	σ_X	σ_Y	GNSS point names	Values of horizontal movement along the X-axis, mm	Values of the horizontal motion along the Y-axis, mm	σ_X	σ_Y
			Mean square error for X	Mean square error for Y				Mean square error for X	Mean square error for Y
Karjantau fault									
xum1	2.5	4	±1.9	±2.8	chr1	1.5	6.5	±0.9	±3.9

Continued

xum2	13	22	±8	±13.2	chr2	8.5	5.5	±4.9	±5
xum3	5	4.5	±3.3	±3.2	chr3	3	4.5	±2.4	±3
xum4	−3	−4.5	±2.9	±4.4	chr4	2	−2	±1.3	±3.5
xum5	−6	3.5	±4.6	±3	chr5	−0.5	0	±1.2	±2.7
xum6	−5.5	−1.5	±3.7	±1.5	chr6	−4	−5	±2.5	±3.2
xum7	−5.5	−7.5	±4	±5.4	chr7	−2	−3	±1.5	±3.5
xum8	−5	−5	±3.5	±4.7	chr8	1.5	6	±0.9	±3.5
xum9	−6	−9	±3.7	±5.6	chr9	−1.5	−2	±1.7	±2.6
North Fergana fault									
chd2	1.5	5.5	±0.9	±3.2	gov2	4	6.5	±2	±3.1
chd3	1	0	±0.6	±1.7	gov3	6	9.5	±3.3	±5.5
chd4	0.5	−6.5	±0.6	±5.8	gov4	1	2.5	±0.9	±1.5
chd5	2.5	4.5	±1.5	±2.8	gov5	3	6	±1.5	±3.1
chd6	2	6	±1	±2.8	gov6	1.5	7	±1.2	±3.5
chd7	−1	1.5	±0.7	±0.7	gov7	−3	−3	±1.6	±2.0
chd8	0	−1	±0	±1.2	gov8	1	8	±1.5	±5.0
chd9	−1	−5	±0.9	±4.2	gov9	−3	−5.5	±1.6	±2.6
chd10	0.5	3.5	±0.9	±2.1	gov10	−3.5	−27.5	±1.9	±15.8

The calculation process consists of several sequential steps:

- Preparation of initial data;
- Clarification of satellite orbits;
- Equalization of phase measurements;
- Evaluation of final geodetic parameters.

Reducing atmospheric impact is of particular importance in data processing. To this end, modern correction models were used, taking into account the influence of the ionospheric and tropospheric layers on signal propagation. The results obtained were compared with data from the permanent stations of the International GNSS Service (IGS) (Herring et al., 2018). This made it possible to verify the compliance of the results with international standards and reduce errors.

At the final stage, two main scientific results were formulated (Shukurov, 2018):

- Time series were compiled for each observation point, and the dynamic movement of the points was analyzed;
- Absolute and relative displacement velocities were calculated in tabular form results.

As a result of the comprehensive processing of GNSS data, the high-precision coordinates of GNSS stations installed in the Tashkent and Namangan regions, as well as their average annual movement speeds, were determined. In GNSS observations conducted along the Chirchik, Xumsan, Chodak, and Gova profiles, horizontal displacement vectors and movement velocities were calculated for each observation point, and based on them, the horizontal movements of the Earth's crust are presented in the table (**Table 2**) and the maps (**Figure 2**).

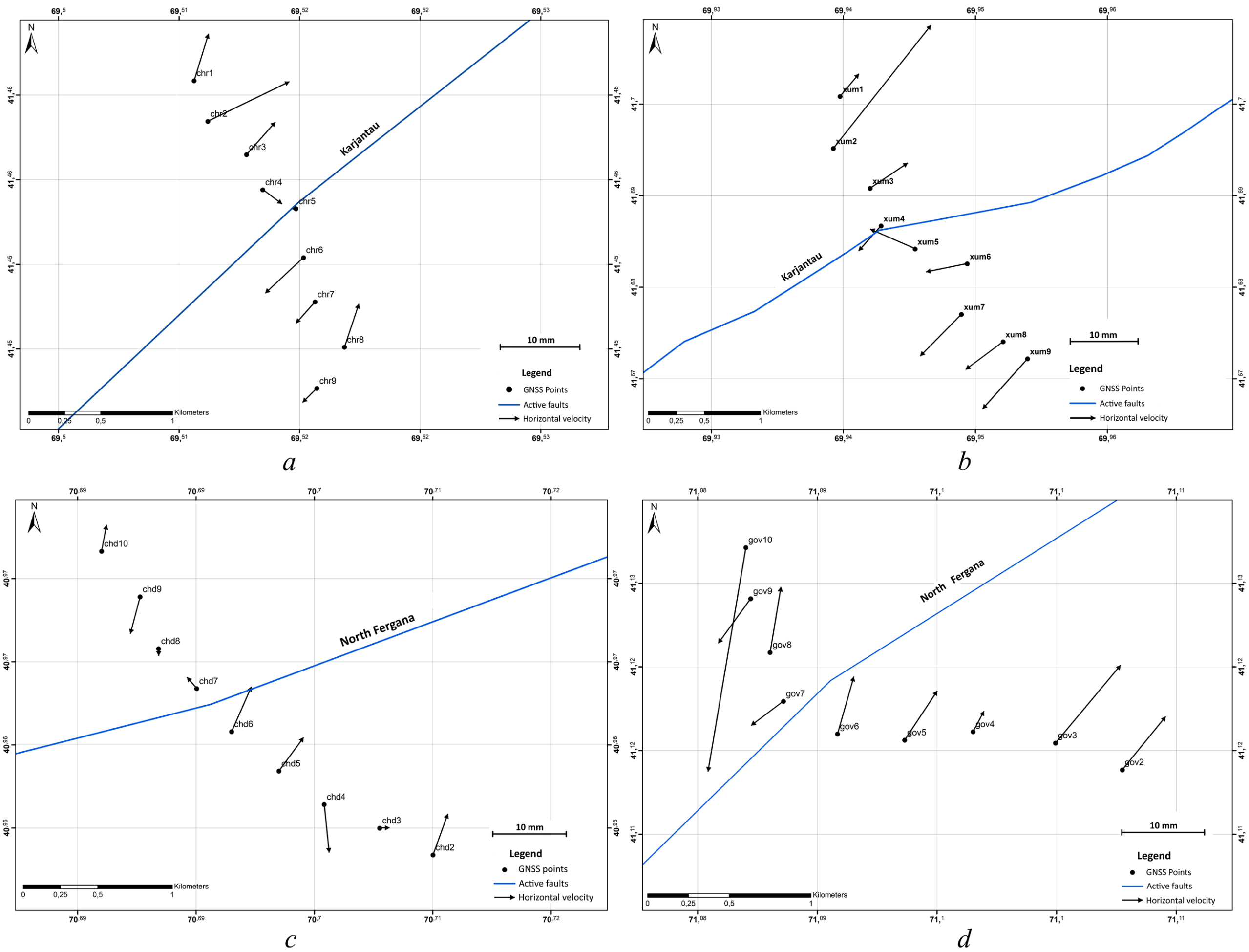


Figure 2. Horizontal movement directions of GNSS stations: (a) Chirchik profile; (b) Xumsan profile; (c) Chodak profile; (d) Gova profile.

2.2. Analysis of GNSS Results

GNSS survey results indicate that the study area possesses a complex geodynamic environment formed under the interaction of large tectonic blocks. The observed horizontal displacements confirm that different parts of the Earth's crust are moving in different directions and at different speeds. In particular, the direction of movement identified in active fault zones was evaluated. The results of geodynamic monitoring showed that horizontal movements at the marks located along the Xumsan and Chirchik geodetic profiles in the Tashkent region, as well as the Chodak and Gova geodetic profiles in the Namangan region, develop according to a specific pattern and are directly linked to major tectonic structures.

Specifically, significant relative displacements between tectonic blocks under the influence of the Karjantau fault zone were identified along the Xumsan and Chirchik profiles. The results of the initial cycle of GNSS observations confirm that modern geodynamic processes are actively ongoing in this zone, and displacement deformations persist at the current geological stage. Blocks located on opposite wings of the fault exhibit varying displacements in horizontal directions, indicating a direct correlation with the tectonic structure of the area.

It should be noted that these conclusions are based on preliminary estimates obtained from the first cycle of GNSS observations. Nevertheless, the observed opposite-directional movements indicate that modern geodynamic movements are actively continuing along the Karjantau fault.

The results obtained on the Chodak and Gova profiles in the Namangan region showed the presence of relative movements in opposite directions in various segments of the North Fergana fault. The high displacement value in rappers located near the crack confirms the activity of deformation processes primarily in the zone of the crack.

In the future, increasing GNSS observation cycles and continuing regular geodetic monitoring will allow for a more accurate quantitative assessment of the current stress-strain state of the Karjantau and North Fergana fault zones. Overall, the GNSS results confirm that large tectonic faults in the Tashkent and Namangan regions are characterized by active geodynamic processes at the modern stage. The uneven distribution of deformations and the high shear values in certain segments are of great scientific and practical importance for assessing the seismotectonic state of these territories and identifying potential hazard zones (Figure 3).

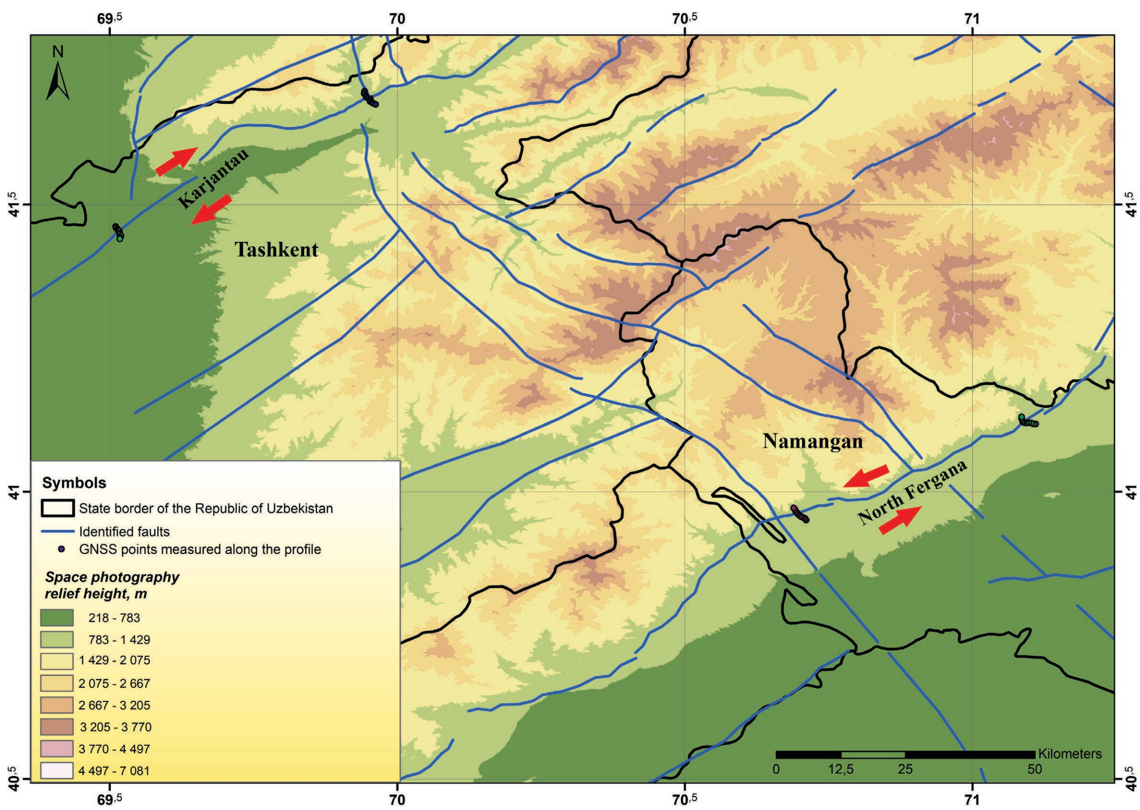


Figure 3. Horizontal displacements identified based on GNSS data along the Karjantau and North Fergana faults.

Figure 3 shows modern horizontal tectonic movements determined based on GNSS measurements and the spatial positioning of faults. In this case, the relative displacement directions of the tectonic blocks observed in the Karjantau and North Fergana fault zones are represented by red arrows.

In the Karjantau fault zone, located northwest of Tashkent, horizontal directions are characterized by the movement of blocks located on two wings of the fault in opposite directions. The direction of the arrows indicates the presence of left and right lateral displacement elements between the southern and northern blocks of the fault. This situation indicates that tectonic movements are continuing in the region.

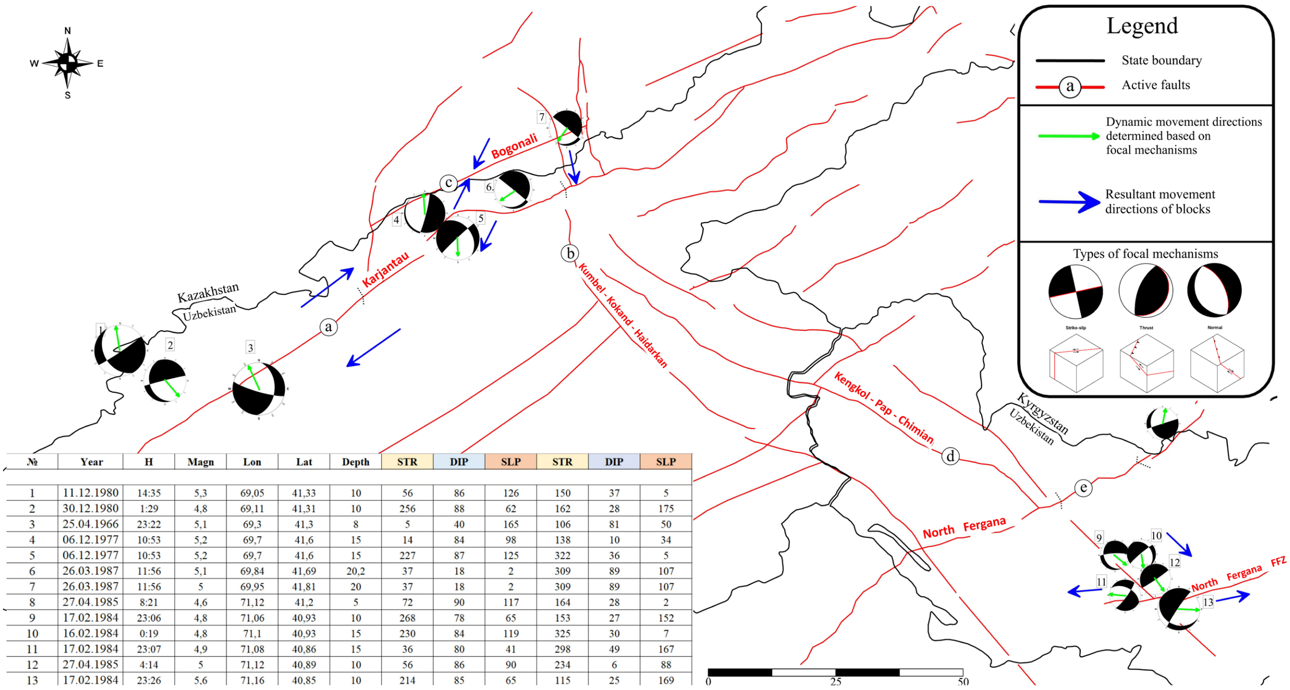
Significant horizontal displacements were also recorded in the North Fergana fault zone near the city of Namangan (**Figure 3**). This situation is characterized by the strike-slip nature of the fault, indicating the redistribution of tectonic stresses in the Fergana Valley and adjacent territories.

Horizontal movements identified based on GNSS data are crucial for assessing the modern geodynamic state of the Earth's crust. As a result of the mutual displacement of tectonic blocks, stress energy accumulates in fault zones, and its sharp relaxation can lead to the occurrence of seismic phenomena. Therefore, the Karjantau and North Fergana faults are among the active seismic structures in the territory of Uzbekistan, and their regular monitoring is necessary. The results of GNSS observations show that the horizontal displacements of the marks measured on the Xumsan and Chirchik profiles (Tashkent region), as well as the Chodak and Gova profiles (Namangan region), develop according to a specific pattern. Specifically, intensive geodynamic processes are observed in the Karjantau fault zone along the Xumsan and Chirchik profiles, confirming the current activity of the area.

The results of the Chodak and Gova profiles in the Namangan region show that relative movements in opposite directions persist between the two faults. In near-fault marks, high displacement gradients are consistently observed throughout the North Fergana fault system. This confirms that the area is in an active geodynamic regime, and the uneven distribution of deformations is an important indicator for assessing future seismic activity.

Further analysis showed that modern horizontal movements of tectonic blocks in the Karjantau and North Fergana fault zones occur in opposite directions. In the zone of the Karjantau fault, northern blocks are moving to the northeast, while southern blocks are moving to the southwest; in the area of the North Fergana fault, opposite movements are observed. This circumstance indicates that the geodynamic block bounded by the Karjantau and North Fergana faults moves southwest as a single whole. Analysis results based on focal mechanisms.

Analysis of the focal mechanisms observed in this region indicates that a combination of several processes is being observed here, rather than a single type of tectonic movement. That is, the processes of strike-slip (lateral displacement), reverse (uplift due to compression), and oblique-slip (inclined displacement) occur together. This indicates that the area has a geodynamic block structure (**Figure 4**).



№	Year	H	Magn	Lon	Lat	Depth	STR	DIP	SLP	STR	DIP	SLP
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4	06.12.1977	10:53	5,2	69,7	41,6	15	14	84	98	138	10	34
5	06.12.1977	10:53	5,2	69,7	41,6	15	227	87	125	322	36	5
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7	26.03.1987	11:56	5	69,95	41,81	20	37	18	2	309	89	107
8	27.04.1985	8:21	4,6	71,12	41,2	5	72	90	117	164	28	2
9	17.02.1984	23:06	4,8	71,06	40,93	10	268	78	65	153	27	152
10	16.02.1984	0:19	4,8	71,1	40,93	15	230	84	119	325	30	7
11	17.02.1984	23:07	4,9	71,08	40,86	15	36	80	41	298	49	167
12	27.04.1985	4:14	5	71,12	40,89	10	56	86	90	234	6	88
13	17.02.1984	23:26	5,6	71,16	40,85	10	214	85	65	115	25	169

Figure 4. Focal mechanisms and modern movements of the Earth's crust.

To provide a detailed assessment of the geodynamic and seismotectonic state of the Karjantau fault zone, a combined analysis of earthquake focus mechanisms and GNSS data was conducted, and a comprehensive map of them was compiled (**Figure 5**).

Mechanism No. 1 in **Figure 5** primarily represents deformation of an oblique-slip nature. The asymmetrical arrangement of the compression and tension quadrants in the diagram indicates that tectonic stress has both a lateral and a vertical component simultaneously. The movement directions are developed in a north-west ↔ south-east orientation, which indicates the presence of a transpressive regime in the area. The mechanism represents the partial lifting and lateral displacement of blocks along an active fault. Mechanisms of this type are usually associated with transform fault segments that develop against the background of regional stresses. Mechanism No. 2 has a displacement character. The almost vertical arrangement of the surfaces and the symmetrical distribution of the opposite quadrants indicate a predominance of horizontal displacement. In this case, the main deformation occurs with lateral displacement along the crack. The stress field is characterized by east-west compression and north-south extension. The mechanism indicates the tectonic redistribution of blocks in the region and the presence of sharp deformations. Mechanism No. 3 belongs to the type of reverse sliding in a complex inclined position. The diagram shows the predominance of the compression component, but an element of lateral displacement is also clearly observed. This mechanism indicates the dominance of regional compression stress in the area and the convergence of blocks along the fracture zone. From a tectonic perspective, this situation is related to the processes of the Earth's crust's uplift. Mechanism No. 4 represents an inclined displacement in which the elements of normal displacement predominate. The arrangement of the black and white sectors in the diagram corresponding to vertical elongation indicates that the lithosphere has transitioned to a local elongation regime. This indicates the formation of tensile stresses in deep fault zones. The probability of block subsidence and gravitational relaxation processes in the region is considered high. Mechanism No. 5 represents a transpressive slip deformity. Although the main part of the movement is related to lateral displacement, there is also a vertical component. This mechanism was formed as a result of the intersecting deformation action of active tectonic blocks. The stress field is complex, with simultaneous compression and shear deformations. This indicates the high activity of the fracture zone. Mechanism No. 6 represents a deformation of the inverse inclined type. The predominance of compression sectors indicates the dominance of the compression stress regime in the region. As a result of the blocks approaching each other, the compression component reached an intensive state. This mechanism is characteristic of foothill zones or collisional tectonic environments. At the same time, the presence of a diagonal displacement element indicates that the tectonic stresses are not uniform. Mechanism No. 7 is close to almost pure sliding deformation. The vertical orientation of the surfaces and the classical appearance of the sectors represent lateral tectonic movements. There is a large deep fault zone in the area, and the blocks are displaced horizontally relative to each other. This mechanism may be genetically linked to active transform-type faults.

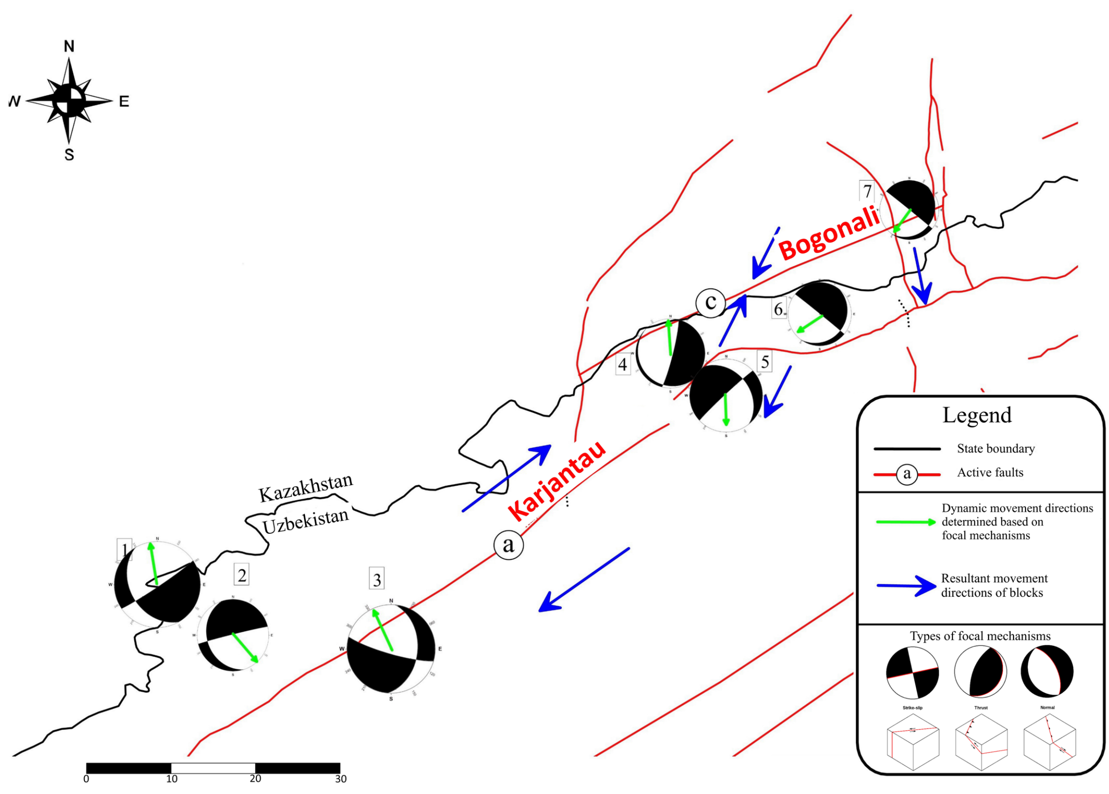


Figure 5. Map of horizontal movements and focal mechanisms of the Karjantau fault zone.

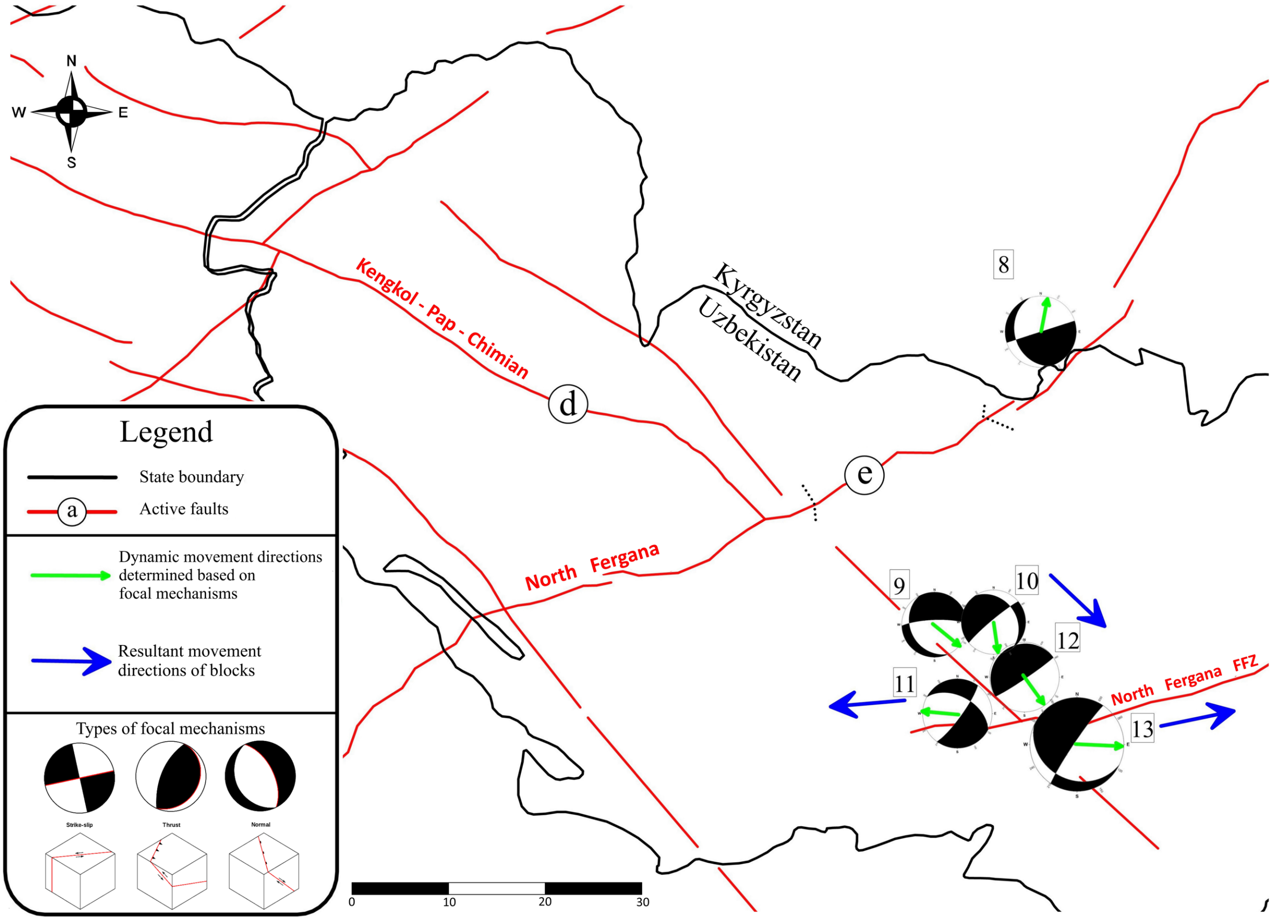
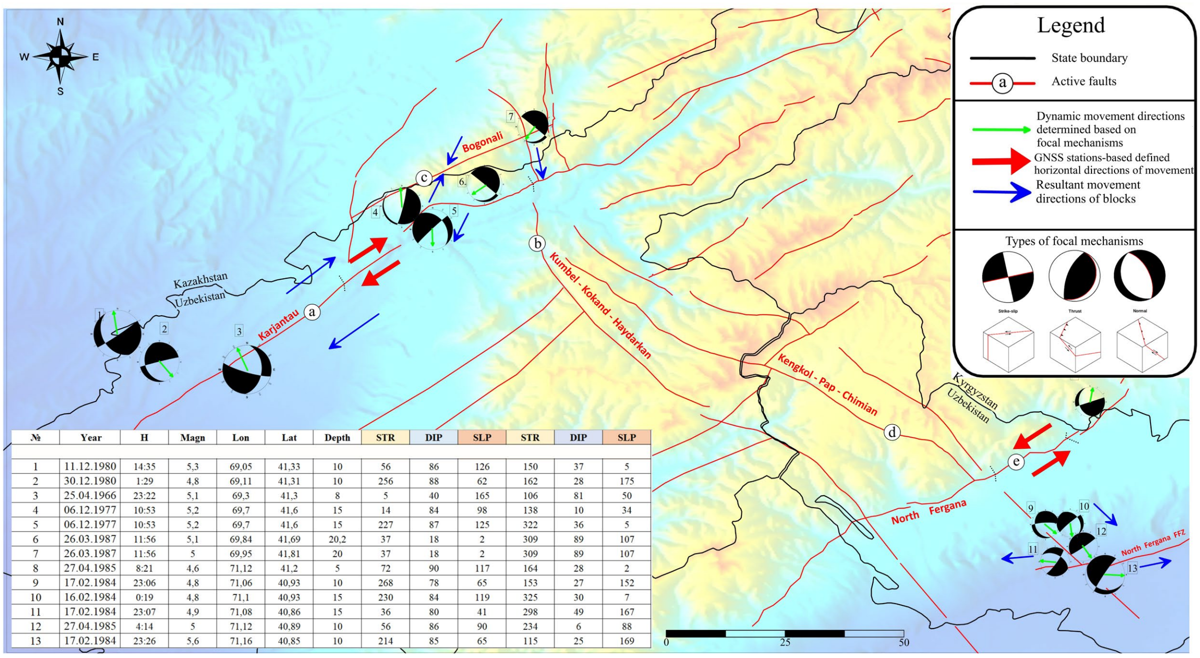


Figure 6. Focal mechanism in the Kenkol-Pap-Chimion and North Fergana fault zones.

Mechanism No. 8 in **Figure 6** has a normal-inclined deformation character. The tensile components in the diagram indicate the presence of tensile stress in the region. Tectonically, this phenomenon is associated with the fragmentation of the lithosphere or a zone of local elongation. Mechanism No. 9 consists of a combination of shear and reverse shear elements. This mechanism is a classic example of transpressive deformity. Along with the mutual compression of the blocks, lateral displacement along the crack also occurs. This situation reflects the transition of the stress field to an intensive state as a result of regional compression. Mechanism No. 10 represents a complex inclined displacement mode. Based on the diagram, it is observed that the main stress axes are developed in a diagonal direction. This indicates the presence of multiphase deformation processes in the region. Although lateral displacement predominates among the components of motion, vertical deformation also plays an important role. Mechanism No. 11 represents left-sided shear deformation. As a result of horizontal stress redistribution, the blocks have shifted in opposite directions. This mechanism is characteristic of shear tectonic zones, indicating an increase in stress resulting from shear in the region. This indicates that the bulk of the seismic energy is released through lateral movement along the Earth's fault. Mechanism No. 12 belongs to the type of inclined reverse sliding. The high compression component indicates the predominance of tectonic contraction processes in the region. At the same time, the diagonal displacement indicates uneven deformation of the blocks. The mechanism confirms that the stress field resulting from a regional collision is active. Mechanism No. 13 represents a large-amplitude shear deformation. The arrangement of the sectors in the diagram indicates a strong horizontal shear strain. There is a high probability of the presence of a large transform or cutting fault segment in the area.

In the analyzed focal mechanisms, lateral displacements and inclined movements predominate, indicating the active movement of tectonic blocks along deep faults. The predominance of compressive forces in certain mechanisms indicates that uplift processes continue in foothill and mountainous areas. The signs of elongation observed in some places indicate the complexity of the Earth's crustal structure and the presence of energy-consuming zones. The prevalence of active faults confirms the high seismic activity of the area. Analysis of the mechanisms shows that these faults are still active in the present period, which means that there is a high probability of earthquakes in the future.

The results obtained are in good agreement with seismotectonic studies conducted at the international level. The deformation regimes identified in the study area, where the components of lateral displacement, inclined displacement, and compression predominate, are confirmed by the developed theoretical approaches to the geodynamic interpretation of earthquake focus mechanisms (Aki & Richards, 2002). The mechanisms of earthquake focuses observed in the Karjantau and North Fergana fault zones indicate that modern tectonic deformations and the movement of tectonic blocks continue in the region (Figure 7).



№	Year	H	Magn	Lon	Lat	Depth	STR	DIP	SLP	STR	DIP	SLP
1	11.12.1980	14:35	5,3	69,05	41,33	10	56	86	126	150	37	5
2	30.12.1980	1:29	4,8	69,11	41,31	10	256	88	62	162	28	175
3	25.04.1966	23:22	5,1	69,3	41,3	8	5	40	165	106	81	50
4	06.12.1977	10:53	5,2	69,7	41,6	15	14	84	98	138	10	34
5	06.12.1977	10:53	5,2	69,7	41,6	15	227	87	125	322	36	5
6	26.03.1987	11:56	5,1	69,84	41,69	20,2	37	18	2	309	89	107
7	26.03.1987	11:56	5	69,95	41,81	20	37	18	2	309	89	107
8	27.04.1985	8:21	4,6	71,12	41,2	5	72	90	117	164	28	2
9	17.02.1984	23:06	4,8	71,06	40,93	10	268	78	65	153	27	152
10	16.02.1984	0:19	4,8	71,1	40,93	15	230	84	119	325	30	7
11	17.02.1984	23:07	4,9	71,08	40,86	15	36	80	41	298	49	167
12	27.04.1985	4:14	5	71,12	40,89	10	56	86	90	234	6	88
13	17.02.1984	23:26	5,6	71,16	40,85	10	214	85	65	115	25	169

Figure 7. Spatial consistency of the main deformation directions restored by the focal mechanisms of the earthquake foci and the horizontal displacement vectors determined by GNSS stations.

The movement directions (blue arrows) reconstructed from earthquake focus mechanisms around the Karjantau fault are highly consistent with the horizontal deformation directions (red arrows) identified by GNSS stations, indicating that tectonic processes in the area are stable and directed.

In the North Fergana fault zone, partial consistency is observed between seismic mechanisms and GNSS data; however, a complex and uneven deformation regime with a predominance of lateral, compressional, and inclined shear components, as well as the presence of local anomalies, is identified.

3. Discussion and Conclusion

The results of GNSS observations showed the relative movement of tectonic blocks along the Karjantau and North Fergana faults. According to data obtained along the Chirchik, Xumsan, Chodak, and Gova profiles, blocks located on opposite faults are shifting in different directions. In particular, higher displacement velocities in GNSS marks located near faults indicate that deformations are primarily concentrated in active fault zones. The results obtained also showed that the geodynamic block bounded by the Karjantau and North Fergana faults generally moves in a southwesterly direction.

Analysis of the mechanisms of the earthquake foci revealed that side-slip (strike-slip), reverse-slip (reverse), and oblique-slip (oblique-slip) deformations predominate in the area. In some areas, compression processes were strong, while in others, lateral displacement and local elongation elements were observed. These results confirm the presence of a complex block tectonic structure in the study area, as well as the active continuation of geodynamic processes.

A comparison of the results of GNSS observations and the mechanisms of earthquake foci showed that they complement each other well. The horizontal movement directions identified by GNSS stations in the Karjantau fault zone almost coincided with the movement directions reconstructed from focal mechanisms. In the North Fergana fault zone, although the general directions coincide, small differences were observed in certain areas due to local deformations.

The results of both independent methods confirmed each other, showing that the Karjantau and North Fergana faults are modern geodynamically active zones. The results obtained serve as an important scientific basis for determining modern movements of tectonic blocks, identifying areas of deformation accumulation, and more reliably assessing the seismic hazard of the region.

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Conflicts of Interest

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

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