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POSSIBILITIES OF LINEAMENT ANALYSIS OF DEM SRTM DURING GEODYNAMIC ZONING OF SEISMIC HAZARDOUS TERRITORIES

(on the example of the North-Tien-Shan region)

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Abstract

Lineament analysis of space images can be successfully used for the purposes of formalized analysis and development of maps of geodynamic zoning with the ranking of the study area into areas that differ in the degree of relative geodynamic activity.
As calculated indicators of geodynamic (neotectonic) activity, the density of faults, megacracks and other lineaments, expressed by their total length per unit area, was used. Therefore, the parameter "density of strokes" is taken as the basis for the taxonomic division of the study area into regions according to the degree of tectonic disturbance of the earth's crust. All constructions are implemented on the basis of lineament analysis included in the CATALIST software package (Canada)
On the example of two seismically hazardous regions of the Northern Tien Shan (Almaty and Zhambyl), the distribution features and properties of lineament density parameters are illustrated, followed by the construction of maps of geodynamic activity.
The lineament analysis of the DEM SRTM of the regional level of generalization made it possible to establish the main features of the geodynamics of the regions - Zhambyl and Almaty regions at the present stage.
The results obtained have proven their effectiveness and the ability to conduct an objective assessment of the seismicity of the territories, the reliability of which is confirmed by seismological and other ground-based observation data.

Keywords: geodynamics, seismicity, lineament analysis, zoning, seismic risk

I. Introduction

Lineament analysis of space images, which became widely known thanks to the work of Zlatopolsky A.A. [4]., Bondura V.G. [1], Kopylova I.S. [5], etc., can be successfully used for the purposes of formalized analysis and development of maps of geodynamic zoning with the ranking of the study area into areas that differ in the degree of relative geodynamic activity.

It was found [5] that one of the most important calculated indicators of geodynamic (neotectonic) activity is the density of faults, megacracks and other lineaments, expressed as their total length per unit area. Therefore, the parameter "density of strokes" is taken as the basis for the taxonomic division of the study area into regions according to the degree of tectonic disturbance of the earth's crust.

But the network of lineaments reflects not only the structural block divisibility of the lithosphere, but also its integral and modern stress state, which manifests itself in different orientations of fault systems that characterize modern geodynamic activity of various scales, from planetary to local. Maps that make it possible to judge the distribution of possible areas of increased geodynamic risk are maps of the density of the intersection nodes of differently directed lineaments.

Thus, the use of lineament analysis of space images provides complexity and consistency as necessary components of solving the problems of identifying zones of geodynamic activation and, in particular, on the territory of the Tien Shan seismically active region.

II. Methodology

Characteristics of the fault tectonics of the North-Tien-Shan region

The territory of the North Tien Shan region is a vast area of modern geodynamic processes, located within the boundaries [(67-75) o in longitude and (39-43) o N], which by the time of formation belongs to the Paleozoic.

It is believed that the Late Cenozoic orogeny of the Tien Shan was caused by the collision of the Hindustan continent with Eurasia. The kinematics of active faults and GPS data indicate that the direction of horizontal compression of the Tien Shan region at that time was close to meridional [12].

The main conclusion of the author [9] is that "during the Late Cenozoic deformation of the Tien Shan, in most cases, new faults did not arise, but movements along the Paleozoic faults occurred." That is, the Late Paleozoic faults "revived" in the regional deformation fields that arose during earthquakes [9,10].

The fault tectonics of the Zhambyl and Almaty areas of study are characterized by rose-direction diagrams (Figure 1-A, B), built according to the DEM SRTM and [7].

A

Rose diagrams of faults
Total - 453- 453
Total length(м) – 6 249 565,677

B

Rose diagrams of faults
Total - 745
Total length (м) - 20 138 143,58

Fig. 1: *Rose diagrams of faults in Zhambyl (A) and Almaty (B) regions North-Tien-Shan region according to the DEM SRTM*

Comparison of the radiation pattern (Figure 1-A) constructed for 453 faults identified by the SRTM DEM in the Zhambyl sector of the North Tien Shan region with the patterns given in [9] suggests that most of them can be attributed into the category of active ones, i.e., those in which progress occurred in the recent past and, therefore, is possible in the near future [13].

An analysis of the distribution of all faults identified by the DEM SRTM (745 faults) for the Almaty sector showed that the sublatitudinal strike direction of about 75o is dominant and statistically significant (Figure 1-B). It is with this direction that most of the distinguished elements of fault tectonics are associated, which coincides with the strike of modern geodynamically active faults and corresponds to the main strike of mountain ranges in this region

I would like to emphasize that, according to the authors of [15], the Northern Tien Shan is undergoing intense compression in the north-north-west direction, which corresponds to the sublatitudinal strike of ridges, depressions, faults, and other structural elements. But at the same time, it "is in conditions of vertical expansion, which manifests itself as an uplift of the earth's surface"[15]. Such a ratio of forces of external influence inevitably generates inhomogeneities of the deformation field and movements of the earth's crust, leading to the conclusion about the existence of blocks of the earth's crust moving at different speeds, which "interacting with each other, change their position and deform" [15].

The characteristics of such blocks are considered in detail in [11].

To complete the characterization of the nature of the seismicity of the region, we note that, according to the results of complex geophysical studies in the structure of the earth's crust of the Tien Shan, a feature was revealed - "the existence in its composition of two parts: the upper - brittle, 16-25 km thick and the lower - plastic thickness of 30-35 km " [14].

Observations of the hypocentricity of the sources showed that the sources of earthquakes with M ~ (2.5 − 4.5) occurred at depths of 5–25 km; Almost all earthquakes are recorded in the fragile layer of the Earth's crust [14].

And the very nature of seismicity is explained by the structure of the upper mantle - the existence of areas of deconsolidation on a cut, 67 km deep (crust / mantle boundary zone), which became the main reason for the intensive uplift of these mountain systems. According to the authors of [13], plumes and associated intramantle flows are the source of left-handed displacements along sublatitudinal faults.

Methodology for processing and building maps

The advantage of DEM over optical images is that only relief elements are involved in the analysis and brightness anomalies caused by other sources (vegetation, technogenic objects) are excluded, which means that there are no errors in assessing the presence of structures of a different direction [5].

In order to select a variant that emphasizes the systems of the known fault-block divisibility of the North Tien Shan region in the most contrast, known fault lines were superimposed on the maps.

For their processing and construction, a standard set of software for lineament analysis of the PC "CATALIST" ("GEOMATICA"), ArcGIS, as well as author's programs were used. The processing parameters were selected empirically, i.e. subjectively. These are the search radius - 5 km and the minimum length of the stroke (fault) - 2 km.

To build maps of geodynamic activity, the lineament density parameter was used, which in the context is identified with the density of faults, megafractures, expressed in their total length per unit area and can be used as one of the indicators of geodynamic activity [5].

III. Results

Characteristics of directionality and density of lineaments in the territories of regions

The purpose of this study is the development and verification of maps of regional geodynamic activity based on the lineament analysis of the DEM SRTM of the average spatial resolution of the territories of the Zhambyl and Almaty regions of the North Tien Shan region.

Zhambyl region

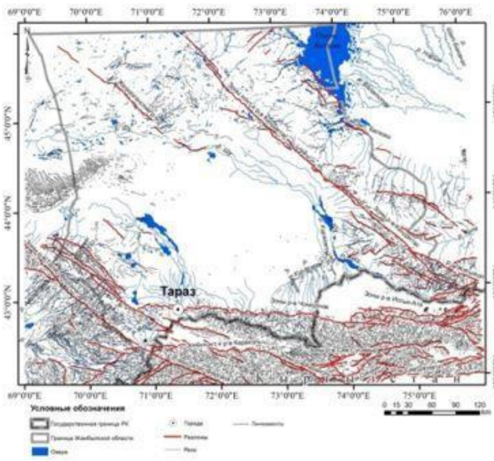
As already noted, as the initial data, materials of the first level (Level-1) radar topographic survey (Shuttle radar topographic mission (SRTM)) with a resolution of 30 meters were used, which approximately corresponds to the topographic base at a scale of 1: 100,000

As a result of processing the SRTM DTM, maps of the distribution of lineaments were built, which were subsequently converted into density maps, followed by the construction of a rose pattern (Fig. 2).

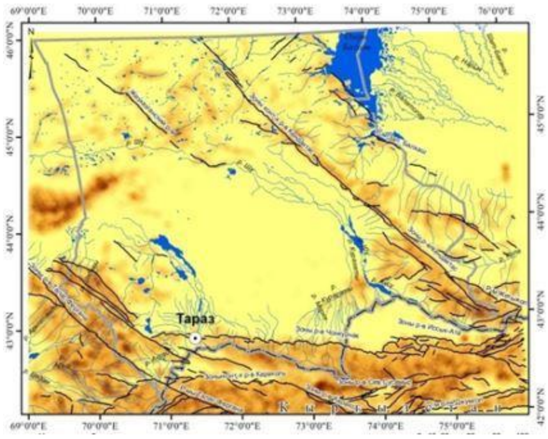
It is obvious that the distribution of lineaments over the area can be called multidirectional and does not unambiguously characterize unconditionally and in detail the fragmentation of the earth's crust. One can rather assert about the different spatial organization and mapping of the structural features of the relief. But at the same time, the integral component of their distribution and the strike of fault lines, of course, correlate with each other (Fig.2, A). This fact shows itself well on the lineament density map (Fig.2, B).

In essence, areas of high density values can indicate the presence of a regional fault or its elements, as well as contribute to the identification of ring structures and the formation of an estimate of the block divisibility of the lithosphere and even a number of its other properties related to kinematics and SSS. Therefore, the distribution of lineaments should be considered as a set of systems that reflect the internal patterns of the tectonophysical structure and state of the object of study [6].

A



B



Lineament Rose Chart
Total : 20854
Total length (м): 70 050203,58

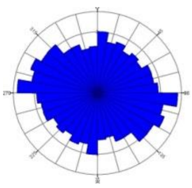


Fig. 2: *Maps of the distribution of lineaments (A) and their density (B) on the territory Zhambyl region.*

The directivity diagram shows (Fig.2) that although the identified lineaments reflect the dominant direction of the known faults (Fig.3), at the same time, it contains a meridian maximum and statistically representative multidirectional elements, which together can characterize the fragmentation of the region's crust.

And here it is useful to consider the distribution of lineaments, or rather their density index in connection with seismicity, as well as their role in revealing hidden faults that are not mapped on the earth's surface.

The relationship between the density of faults, their activation, and the location of earthquake sources was previously considered in a number of works for various regions [2, 8, etc.]. It is shown that manifestations of seismicity are most likely where there is a high fracture density. And even, moreover, a direct correlation between the density of faults and magnitude has been established.

But at the same time, it is noted that a fragmented medium is not able to accumulate significant stresses necessary for the occurrence of strong earthquakes and is characterized mainly by weak, but frequent manifestations of seismic activity [2].

The territory of the region is characterized by numerous low-magnitude epicenters of the order M= 4.0-6.0, which cover the entire area, but to a greater extent gravitate towards zones of increased density of lineaments and associated faults.

Such energy of seismicity may indicate a high fragmentation of the region's crust and the possible existence of hidden small blocks that experience multidirectional movements with subsequent discharge of low stresses. Strong earthquakes occur at the boundaries of large-block structures and are confined to zones of medium increased density [2].

Structurization (correlation) of zones of high density of lineaments and known manifestations of seismicity can be more obvious if we consider a map of the density of nodes of their intersection and the distribution of epicenters.

As shown in Fig.3-A, the high-intensity lineament intersections generally correlate well with known fault lines. But in some cases this is not obvious and can be explained by the fragmentation and multidirectionality of block displacements.

The distribution of epicenters does not contradict this conclusion, but it is difficult to visually illustrate the direct dependence due to their mass character and crowding (Fig.3-B). Although in general, it can be argued that the ratio of epicenters and lineament intersection nodes shown in Figure 7 indicates that seismic manifestations are to a certain extent associated with areas of moderate and relatively high density of intersection nodes. This indicator can be considered a conditionally necessary sign of the geodynamic activity of both faults and those structural elements that fall into the zone of their geodynamic influence.

From the comments made on the density maps, it follows that the lines of regional faults are in good qualitative agreement with the strike of the values of the anomalous density of the lineaments and, in the first approximation, they can be used as an indicator of the detection of faults, taking into account the known geological and geophysical data.

The length of lineaments, their density and connection with earthquakes.

If we talk about lineaments as breaks in the continuity of the crust, then it should be taken into account that the magnitude of an earthquake is affected precisely by the length of the lineament [3].

That is, the relative strength of earthquakes depends on the degree of fragmentation of the crust (fault length) and, therefore, it seems necessary to consider the correspondence of this indicator to the North Tien Shan region. Indeed, in essence, this is a mapping of lineaments of different ranks, as projections of deep faults on the earth's surface in their connection with seismicity.

As a result of the constructions, it turned out that there is no differentiation of lineaments of different lengths over the area. but in general, lineaments 1–3 km long predominate. Their density significantly exceeds the density of other groups and especially the 5-20 km group. Although the latter, in fact, are represented everywhere. And, consequently, earthquake epicenters and density anomalies retain their spatial similarity.

This implies the conclusion that large and ubiquitous, but less representative in number, faults can play a significant role in the manifestations of the geodynamic activity of the region.

A B

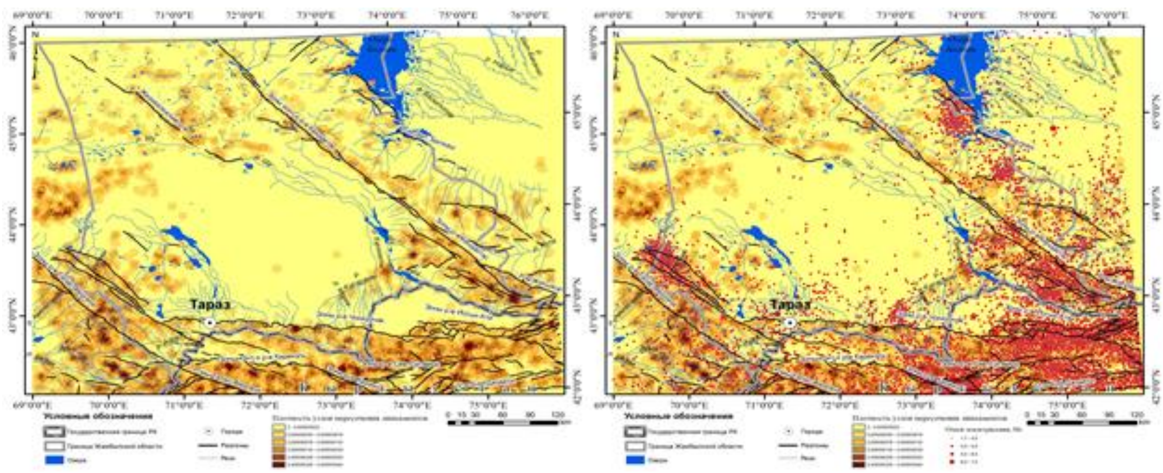


Fig. 3: *Density map of lineament intersection nodes (A) and their relationship with earthquake epicenters (B) of the Zhambyl region*

Characteristics of lineament density maps by directional sectors

The construction of density maps for lineaments of different lengths made it possible to identify directions that are of interest from the point of view of assessing the territorial zonality of a possible manifestation of seismic activity.

A B C D

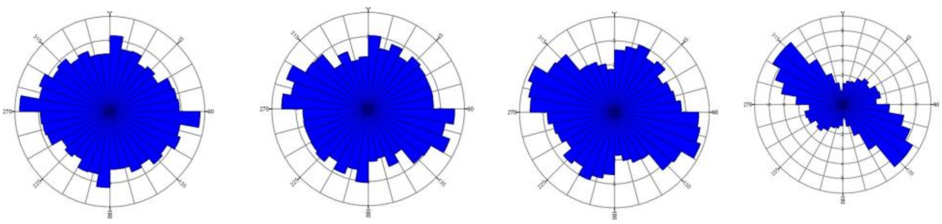


Fig. 4: Rose diagrams for lineaments with length: A - (1-2) km; B - (2-3) km; C - (3-5) km; D - (5-20) km

Taking into account the dominant directions shown in the diagrams (Fig.4), the sectors were determined and the corresponding density maps were built based on the base maps of the density and the density of intersection nodes for lineaments with a length of 2 km.

For the diagram (Figure 4, A), two sectors were chosen: (0-10)^{O} - submeridional and (90-100)^{O} - sublatitudinal.

The distributions of lineament density values obtained for these two directions (Fig.5) showed that the main contribution to the distribution of lineaments over the area with a lineament length of 2 km is associated with submeridional orientation.

Sublatitudinal lineaments dominate in the southern part of the Northern Tien Shan (Fig.5, C). If we turn again to the length, it should be noted that sublatitudinal lineaments with a length of 3 km or more do not make a significant (quantitative) contribution to the overall pattern of lineament distribution density and thereby reduce the seismogenic potential of strong earthquakes in the region. Although, of course, they cannot be ignored.

This implies that seismic activity in the region is mainly due to lineaments up to 3 km long, which form the main and, as mentioned above, a small fault-block structure (Fig.5).

A B

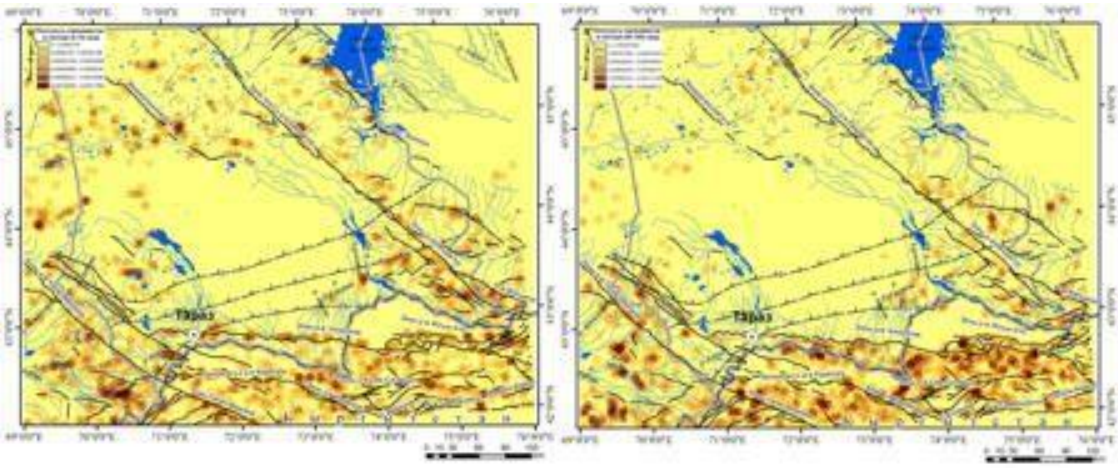


Fig. 5: *Lineament density distributions for sectors: (0-10)^O - A and (90-100)^O - B in the territory of the Zhambyl region*

Lineament Rose Chart
Total: 3 418
Total length (м): 29 144 304,39

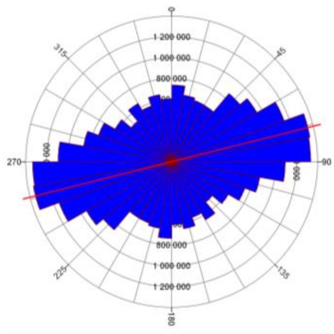


Fig. 6: *Rose-diagram of lineaments of all directions of the Almaty region*

Almaty region

The SRTM DEM of the Almaty region was processed to extract lineaments and build density and node density maps.

An analysis of the distribution of all lineaments identified by the DEM SRTM (3418 pieces) showed that the sublatitudinal strike direction of about 75° is dominant and statistically significant (Fig.6). It is with this direction that most of the distinguished elements of fault tectonics are associated, which coincides with the dominant direction of the faults (Fig.1, C). But, at the same time, a fairly large number of lineaments are associated with others, including submeridional strike (Fig.6).

As well as for the Zhambyl region, the calculation of the lineament density map was carried out for strokes exceeding 2 km in length (Fig.7). The results of the performed calculations are shown in Fig.7 (A, B). It is obvious that the zones of geodynamic activation are associated with areas of the highest density. This is confirmed by the position of the epicenters of all the largest earthquakes (Fig.7, B). As is known [2], the high density of lineaments is associated with fault crossing zones, which, in turn, reflect the geodynamic activity of fault areas.

It has been established that the manifestations of seismicity in the region are to a certain extent associated with areas of moderate and relatively high density of intersection nodes. This indicator can be considered a conditionally necessary sign of the geodynamic activity of both faults and those structural elements that fall into the zone of their geodynamic influence.

But, as mentioned above, the energy of an earthquake to a certain extent depends on the length of the fault associated with it, which is confirmed by the graphs given in [3]. It also states that “an increase in the total density of discontinuities reduces the energy class of controlled earthquakes” [2].

A B

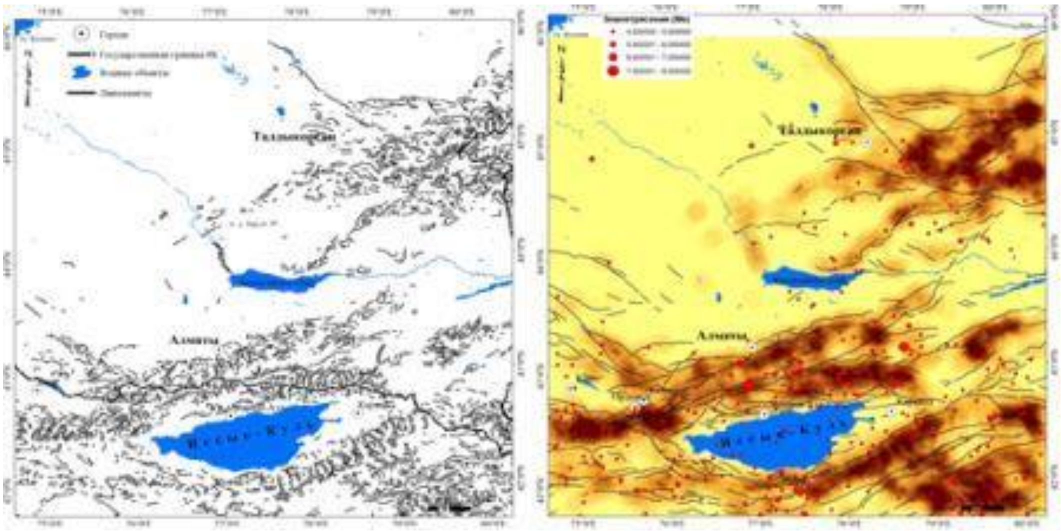


Fig. 7: *Lineament distribution maps (A) and their density (B) of Almaty region (earthquake epicenters are shown according to the COME catalog for 1951-2022)*

That is, the relative strength of earthquakes depends on the degree of fragmentation of the crust (fault length) and therefore it seems necessary to consider the correspondence of this indicator for the Almaty region of the North Tien-Shan region.

The maps below show the density distribution for a conditional stroke (fault) length of 2, 5, 10 and 15 km (Fig.8), as well as a density map of intersection nodes for a conditional fault length of 5 (Fig.9).

There are two points to note when looking at Figure 8. The first is that the territory of the Almaty region, in contrast to the Zhambyl region, is quite sharply differentiated in terms of the values of the parameter under consideration, and, consequently, in terms of possible seismogenicity. And the second is a fairly convincing correspondence between the distributions of a larger number of epicenters and zones of high density values associated with large faults.

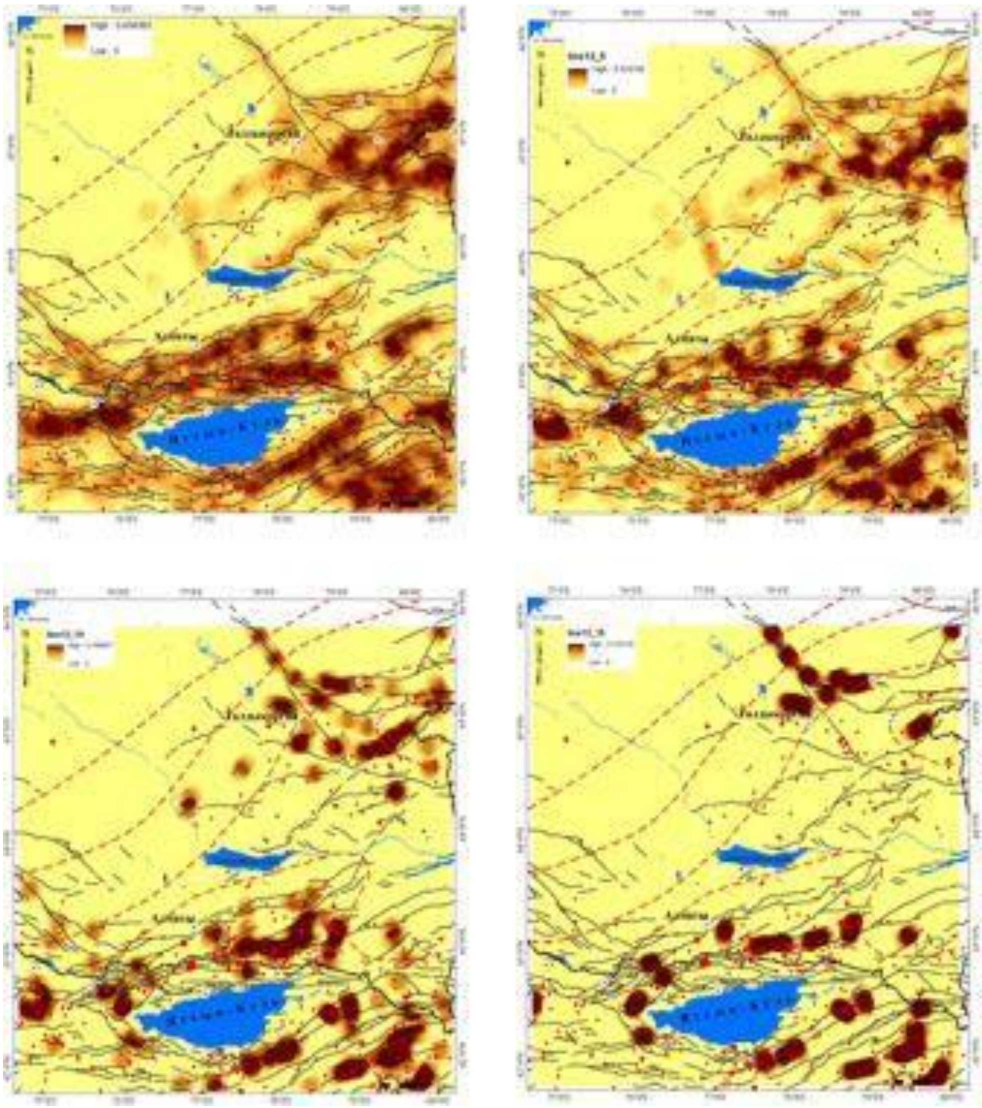
However, one feature cannot be overlooked. The epicenters of earthquakes of energy class 7, located near the city of Almaty, do not fall into any of the marked zones (Fig.8 C, D). This feature, apparently, is due to the structural-tectonic position of this section of the fault, where there is no release of stresses associated with low-amplitude interblock movements accompanied by weak but frequent earthquakes [2].

The features of the structure of this zone, apparently, are such that there is an accumulation of stresses, accompanied by the inevitable rearrangement of blocks and the transition of the system to a state of new geodynamic equilibrium [3]. And this part of the territory, apparently, should be given closer attention in terms of VAT assessment.

Thus, the idea is confirmed that the intense fragmentation of the geological environment does not contribute to the accumulation of those stresses that generate strong earthquakes [2]. This is the general situation, which, of course, may have its own specific features in the manifestation of seismicity.

The density map of lineament intersection nodes shown in Figure 9 reflects the main manifestations of seismicity in the North Tien Shan region for the foreseeable period of time.

A B



C D

Fig. 8: *Distribution maps of lineament density values for conditional lengths of faults (in km): 2-A; 5-B; 10-C; 15-D.*

Obviously, with a conditional fault length of 5 km, one can see both the main sources of earthquakes and the background against which they occur. In particular, the sources of strong earthquakes described above manifested themselves in lineaments (faults) with a length of 5 km.

Characteristics of lineament density maps by sectors

The purpose of this section is to show the possibility of zoning according to directions in connection with seismicity - a preliminary assessment of zones of geodynamic activation.

Preliminary zoning of the territory of the Almaty region of the North Tien Shan region according to the degree of geodynamic activation was carried out on the basis of the distribution of lineament intersection nodes, which essentially fix not only the areas of the highest density of differently directed faults, but also their connection with the directions of the main tectonic faults prevailing in a particular sector and epicenters of known earthquakes.

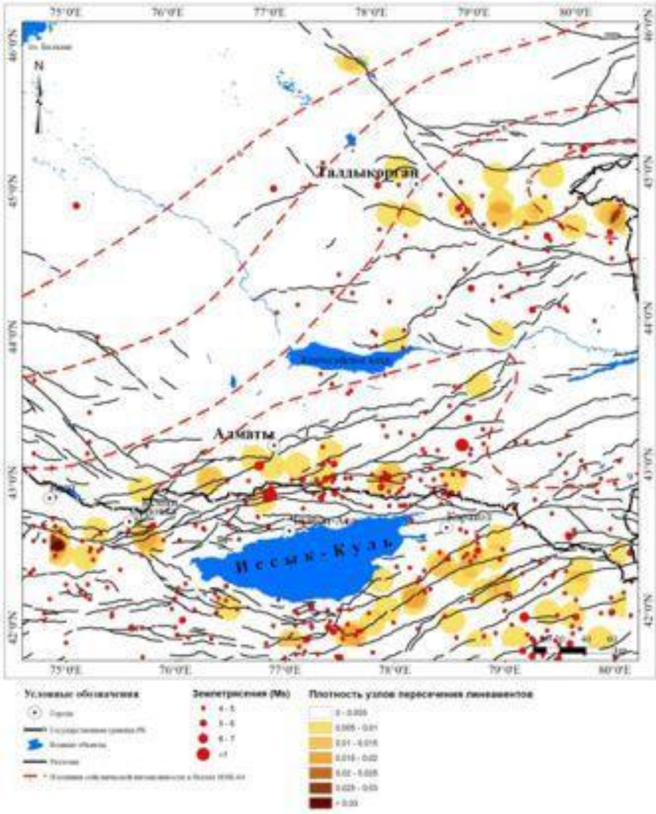


Fig. 9: *Density map of lineament intersection nodes for conditional the length of the fault is 5 km.*

Taking into account the rose diagram shown in Fig.6, a set of maps of the distribution of intersection nodes by sectors was formed, giving a visual representation of the location of zones of geodynamic activation and associated active faults of one direction or another.

Thus, in the sector (0-37)$^{\circ}$, the intersection nodes form a curvilinearly elongated area, passing in close proximity to the city of Almaty, but characterized by earthquakes of relatively small magnitude (4-5). And the epicenters of strong earthquakes are, as it were, in the area of "seismic calm". At the same time, it can be seen that the epicenters of strong earthquakes close to Almaty are associated with faults located in the (140-180)$^{\circ}$ sector. There is also an area elongated in the sublatitudinal direction that controls low-magnitude earthquakes in the southeastern sector. At the same time, the epicenter of a strong, but relatively remote from Almaty earthquake is located in the sector (0-37)$^{\circ}$.

The above example testifies not only to the connection of earthquake sources with zones of high density of lineament intersection nodes, which in turn characterize seismically active faults, but also, most importantly, retrospectively shows the degree of geodynamic hazard of differently directed faults. This circumstance must be taken into account when calculating the degree of seismic hazard associated with the direction of external forces on certain parts of the earth's crust.

Maps of regional geodynamic activity of the territory of the North-Tien- Shan region

In accordance with the methodology for zoning the territory according to the degree of geodynamic activity proposed by A.S. Kopylov [5], an analysis of the SRTM DEM was performed with the construction of lineament maps for the North Tien Shan region and their subsequent ranking in terms of density, expressed in their total length by area unit.

Zhambyl region

Fig.10 shows a map of regional geodynamic activity for the territory of the Zhambyl region.

According to the proposed methodology, relief and lineaments act as a form of displaying a geodynamic activity model that can be ranked and then converted into appropriate maps, from stable to highly active (Fig.10).

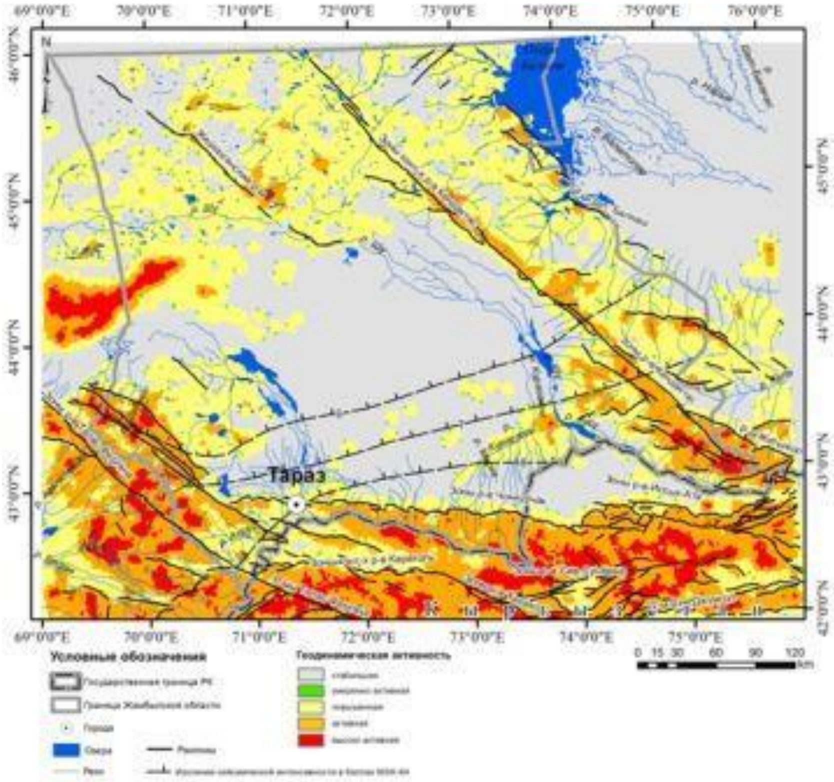


Fig. 10: *Map of regional geodynamic activity of the Zhambyl region*

Upon closer examination of the completed constructions, it can be noted that all highly active areas are located in the zones of geodynamic influence of regional faults. First of all, the Talas-Fergana fault and its continuations in the form of separate fragments located in the southern part of the Tien Shan region stand out.

As a rule, all highly active and active zones are confirmed by the location of the epicenters of weak earthquakes. For example, the Kendyktas fault, located in the active zone, is also marked by a large number of epicenters.

The city of Taraz itself is located in a zone of moderate activity at the junction of two active zones, and an isoseist of 8 points passes through it. But a significant part of the territory is characterized by the degree of geodynamic activity as “stable” and “increased”.

At the same time, the entire southern and flank zones of the region are areas characterized as "active" and "highly active", which are crossed by numerous faults of varying degrees of activation.

Based on the opinion of the authors of [9] and the distribution map of epicenters, it can be assumed that all recent movements are associated with small-block slips without the formation of new large modern ruptures.

That is, the geodynamic activity of the region as a whole can be called moderate with some manifestations of activity in the zones of hidden faults.

Verification of the constructed maps with the map "Typification of the Zhambyl region according to the morphological conditions for the formation of geodynamic processes" showed that fragments of high activity zones correspond to areas of active contrasting recent movements and recent uplifts.

Thus, if we consider lineaments as an indicator of fragmentation of the crust, then, as was established earlier [3, 19], earthquake epicenters gravitate towards zones of increased fault density. Moreover, the higher the density, the higher the magnitude.

But on the other hand, it is known that a fragmented medium is not able to accumulate large stresses and their discharge is accompanied by weak, but frequent earthquakes.

In the region under consideration, by definition [9], all geodynamic processes are inactive and are associated with known regional faults. But at the same time, numerous epicenters of small magnitude indicate that the seismicity of the region is due to small blocks and movements along hidden faults separating them.

To assess the degree of reliability of the results obtained, verification was carried out, which confirmed the main conclusions about the distribution of GAS in the Zhambyl region.

Almaty region

Upon closer examination of the completed constructions (Fig.11), it can be noted that all highly active areas near the city of Almaty are in the zone of geodynamic influence of the Chilik-Kendyktas fault. There are other objects that also require a close study of the manifestations of seismicity.

To increase the reliability of the constructions made and the conclusions that follow from them about regional seismicity, a map of "engineering-geological zoning of Kazakhstan under the conditions of the formation of dangerous geodynamic processes" was used (V.P. Bochkarev, S.A. Novitsky, etc., 2004, M 1:2 000 000) - see inset in Fig.11.

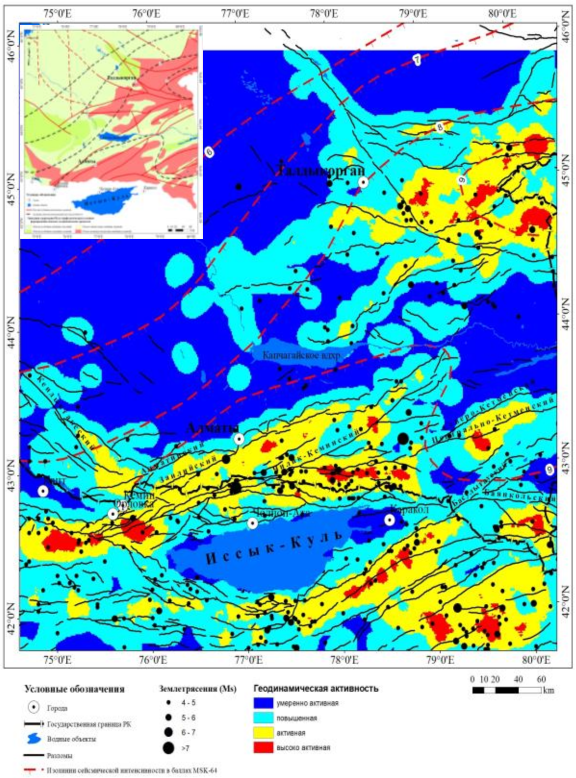


Fig. 11: *Map of regional geodynamic activity of the Almaty region*

Comparing it with maps of geodynamic activity, we can conclude that the areas identified as "active" and "highly active" correspond to areas of significant recent uplifts. There are also areas of the highest geodynamic activity (Fig.11).

It follows from the foregoing that the lineament analysis of the regional level of generalization makes it possible to establish the main features of the distribution of epicenters in their connection with the distribution of the values of the density parameter of the elements of fault-block divisibility in the Almaty region.

The performed zoning made it possible to establish the location of both the seismic calm zone and the zones of increased seismic background.

Thus, the geodynamic analysis of the lineament density made it possible to zoning the territory of the region according to the degree of geodynamic activity. The resulting maps provide a visual representation of the distribution of geodynamically active zones (GAZ), which include areas with high fracturing, characterized by high contrast relative to the background. Large GAS have a complex mosaic structure.

In general, all this gives grounds to believe that the lineament analysis of the SRTM DTM allows for an objective assessment of the seismicity of the territory, the reliability of which is confirmed by seismological and other ground-based observation data.

IV. Conclusion

The lineament analysis of the regional level of generalization made it possible to establish the main features of the geodynamics of the regions - Zhambyl and Almaty regions at the present stage.

The performed ranking and construction of maps of geodynamic activity of the regional level of generalization can be considered indicative in two positions.

In the methodological plan, a technology was tested for using satellite data to solve the problems of regional geodynamic zoning of the territories of seismically hazardous regions.

Moreover, the proposed calculation options generally give an idea of other methodological possibilities of using satellite images in solving seismological problems.

On the other hand, results have been obtained that give an independent idea of the geodynamics of the geological environment with the construction of appropriate maps for ranking territories according to the degree of potential geodynamic activity.

The proposed zoning options and their characteristics cannot and should not be limited to the presented maps. They are the basis for a detailed tectonophysical analysis of the geodynamic situation, including the use of SSS.

In particular, they can be used to establish a correlation between the density of lineaments and earthquake energy, to identify patterns in the spatial distribution of epicenters of strong earthquakes with a degree of fragmentation of the crust, to identify the spatial relationship of earthquakes with fault intersection nodes, to identify the sizes of zones of geodynamic influence of large extended faults, a retrospective analysis of the geodynamic fault activity in the areas of deposits, etc. That is, the solution of those problems that can contribute to the discovery of regular relationships between the manifestation of seismic activation and the geotectonic structure of a particular region, and without which an objective assessment of the seismic potential of seismically active territories is impossible.

Ideally, all these studies should be accompanied by monitoring of displacements of points on the earth's surface of the areas under study with the construction of appropriate maps based on the interpretation of satellite radar data and seismological observations.

Summarizing the above, one can quote Sherman S.I. et al. [2]: “the fault density parameter should be considered more broadly as a very informative indicator of the tectonophysical properties of the fragile lithosphere”, which, in combination with SSS and other parameters, contributes to “the identification of patterns of fault activation and modern fault formation in the lithosphere.”

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