Identification of disjunctive dislocations as one of the parameters for estimating a territory seismicity of North Sakhalin

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Abstract. The north of Sakhalin Island is characterized by frequent earthquakes and many disjunctive dislocations. One of the catastrophic earthquakes occurred in the settlement of Neftegorsk. The level of modern technologies makes it possible to track the change in environmental parameters accompanying dangerous natural processes with a high degree of certainty. The article proposes an interpreting technology for disjunctive dislocations detecting, which differs from the existing ones with the complex use and summation of satellite image data using image processing methods widely applied in "computer vision". The study aims to compile and describe a map of discontinuous faults of the village of Neftegorsk, located in the northern part of Sakhalin Island, using the developed decoding technology and geophysical data. Methods: Identification methods used in the work: 1) methods of primary image processing (correction, transformation, resolution change, cropping, visualization); 2) a set of "contextual" and "autonomous" methods of lineament analysis, with the help of which a series of images is processed (canny, erosion, Hough's algorithm); 3) methods for constructing maps of discontinuous faults (summation, sequential linking). Results. Using the developed technology, a map of discontinuous faults in the area of the Neftegorsk earthquake was constructed. The implementation of the technology makes it possible to provide the monitoring data on discontinuous faults to organizations that are engaged in seismic zoning, construction and operation of objects for various purposes, including mineral deposits.

1. Introduction

That is known that discontinuous faults reflecting deep geodynamic processes are genetically related to seismic processes. Elastic waves resulting from discharge of accumulated energy, are transmitted over long distances and cause the motion of blocks of the Earth's crust [1–4]. The faults, along which the blocks of the earth's crust are displaced separate these blocks and are places of stress discharge. When performing seismic zoning, it is necessary to analyse the distribution of earthquakes of study territory, in which the distance from a fault zone must be considered. These zones are characterized with the presence of linear elements recorded on satellite images [5, 6]. When decoding satellite images, groups of lineaments are revealed that indicate feathering cracks of deep active fault. The more cracks that support the fault, the deeper it is, since the number of cracks indicates geodynamic
activity of the fault. In the areas of discontinuous faults, rocks are mainly characterized with good porosity, filtration, and permeability coefficient. Cracks are caused not only by geodynamic activity, but also by zones of cataclase, mylonitization, brecciation, crushing, slanting, and disintegration associated with them. These factors determine the state of vegetation growing in the fault zone, so these zones are clearly distinguishable in interpreted images [7–9].

2. Methods and materials

The materials for interpreting study territory were the data of satellite images of the Shuttle and Landsat-8 spacecraft [10–12]. The data were subjected to all necessary types of correction. The first level of processing corresponds to the materials obtained from the US Geological Survey website. Landsat8 data are single-channel GeoTIFF images. The materials of the Shuttle apparatus the images obtained using radar interferometric SRTM survey, which have passed procedure of filtering erroneous values.

The initial processing of the images was determined by the initial data needed for analysis in the LEFA program. Images that do not exceed size of 100 pixels are analysed faster. The format of materials uploaded to program must have *.tif extension and geographical reference. Images with different resolutions were introduced, cropping was performed to match the image of the studied area and its detailed analysis. The images were processed in the ArcGIS program [13] in order to obtain the materials with the resolution necessary for further analysis of the territory. The relief forms indicating the zones of discontinuous faults made it possible to identify SRTM materials. They were also processed further in the LEFA software package [14], in which automatic lineament analysis was performed. There are many methods of lineament analysis [15–17]. The results described in the article were obtained using Canny mathematical methods [18] and morphological erosion [19, 20]. The morphological erosion algorithm works on the principle of removing "excess" when comparing an image with a reference, so that their boundaries are determined in the original images [21]. The boundaries of the image determined by the Canny method are captured thanks to the matrix used in the method. The exact boundaries of the image are determined after processing by the double threshold method and the thinning method.

Each image of different resolutions was processed with different sensitivity lines: small, medium and many. The higher the sensitivity, the more lineaments are highlighted in the image. Collinear lines were identified using the Hough Transform [22, 23], which uses linear probabilistic parameters of known quantities of the equation \( y = kx + b \). Determining which lines, according to probability theory, are extensions of each other, the program builds connected collinear lines.

Further integration of modified images and geophysical data was carried out in the QGIS geoinformation system [24]. The modified images were superimposed on each other, as a result of which, according to the greatest coincidence of the lines, considering the digital relief model and seismology data, faults were marked on the map.

The methods of various stages of processing materials to identify discontinuous faults allowed us to draw up a technological scheme for interpreting the faults. The technology includes 7 stages:

1) Search and input of materials suitable for solving the tasks of scientific research.
2) Pre-processing of materials.
   - definition of image boundaries using Canny and Erosion methods;
   - determination of stroke lines using automatic image analysis in the LEFA program;
   - determination of collinear lines indicating the probability of fault location using the Hough Transform;
   - map design, which includes the analysis of lineaments and geophysical data in the QGIS program;
   - map construction and printing.
As result of data transformation by means of the developed technology, a map of disjunctive disorders of the studied territory is created (figure 1).

### Figure 1. Technological scheme of interpreting the fault zones.

#### 3. Results and discussion
When processing the materials of the study territory of North Sakhalin, zones of discontinuous faults were identified and characterized by increased number of cracks (figure 2).

The materials of the lineament analysis obtained after processing the original images show linear-striped textures that characterize the stress-strain state of the Earth's crust. This is due to the good permeability of rocks in fault zones. The obtained materials indicate a high mobility of the Earth's
crust. The recorded lineaments are caused by a change in the stress-strain state of the Earth's crust. The integral effect of the images and seismic data makes it possible to identify the supposed fault structures by means of analysis.

![Image of lineaments and fault structures](image.png)

**Figure 2.** Images with lineaments highlighted into the LEFA program using various methods: 1 – map of Neftegorsk region; 2 – Canny many; 3 – Erosion medium; 4 – Canny medium; 5 – Erosion small; 6 – Canny small.

Earthquakes are located mainly near the faults. Figure 2 shows the areal distribution of the lineaments detected using the morphological erosion method and the local distribution obtained using the Canny method. Modified images with high sensitivity (many) give more detailed information.
about the Earth's surface. The average sensitivity of the lines (medium) draws our attention to some areas of the analysed territory. The low sensitivity of the lines highlights the most pronounced lineaments on the surface, corresponding to long-lasting discontinuous faults. Processed images and SRTM data in the shape file format are analysed in the Quantum GIS software module.

The materials obtained as a result of processing the information about the location of earthquakes and discontinuous faults allow us to judge the nature of the interdependence of seismic activity and fracturing of rock massifs in the fault zones (figure 3). Seismic activity in the fault zone creates structural strength inhomogeneities in the rocks composing it. When selecting lineaments using automated interpretation, the personal component of the interpreter, its subjectivity, is minimized. Software products allow you to see and display what the human eye could miss and not notice. After the lineaments are selected by program, it is time to analyse and forming map in QGIS, where, integrating all the data obtained, certain lines, that form regional and local structural patterns of the Earth's crust, are selected. Then the epicenter points of the earthquakes with the intensity above four points over the last 100 years are added to the map [11], after which the mutual location of point objects (earthquake epicenters) and linear elements is analyzed.

![Symbols](symbols.png)

**Figure 3.** Discontinuities in the area of Neftegorsk earthquake revealed by lineament analysis data and position of epicenters: 1 – Hokkaido-Sakhalin fault (Verkhnepiltunsky segment).

It can be noted on the resulting map, that earthquakes are clearly confined to the zones of discontinuous faults. The areas of the marked earthquakes are characterized with increased stress of the Earth's crust, as evidenced by numerous cracks in fault zones. The western part of the study area is characterized by seismic activity confined to the zone of the Hokkaido-Sakhalin lithospheric fault, previously identified by numerous researchers [25, 26].

Analysis of results has shown that about 90% of earthquakes are confined to the fault zones and are located at 0 to 3 kilometers from them (table 1).

Movements in the fault zones can lead to both material losses and human casualties. Therefore, the zones of discontinuous faults should not be considered as a territory for the construction of important
objects of national economic purpose in order to minimize the risks associated with them. To prevent situations like the one that occurred with Neftegorsk village, a more thorough study of the zones near faults and their comprehensive analysis are necessary [27–29].

Table 1. Distance from the faults to earthquake epicenters in the north of Sakhalin Island.

| Fault name                        | Percentage of earthquakes on Sakhalin Island, confined to the faults, with magnitude greater than 3 for the period 1900–2021, % | The distance from the faults to earthquake epicenters is less than 3 km | Fraction of earthquakes lying near the fault, % |
|-----------------------------------|-----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------|
| Piltun fault                      | 4.6                                                                                                              | 0–1                                                                   | 63                                              |
|                                   |                                                                    | 1–2                                                                   | 6                                               |
|                                   |                                                                    | 2–3                                                                   | 6                                               |
|                                   |                                                                    | 3–4                                                                   | 25                                              |
| Hokkaido-Sakhalin fault           | 20.9                                                                | 0–1                                                                   | 92                                              |
| (Upper-Piltun segment)            |                                                                    | 1–2                                                                   | 2                                               |
|                                   |                                                                    | 2–3                                                                   | 4                                               |
|                                   |                                                                    | 3–4                                                                   | 2                                               |

4. Conclusion
The results obtained deserve special attention, since in addition to the previously known zones, new areas of discontinuous faults have been identified. A more thorough study of this area is needed using large-scale images, as well as a number of geophysical observations. The research materials allow us to propose a fundamentally new approach to the study of discontinuous faults based on space monitoring of the study territory.

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