Results of processing and complex interpretation of geophysical and satellite remote sensing data in the context of environmental management tasks

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Érkezett: 2020. 06. 30. ▪ Received: 30. 06. 2020. ▪ <https://doi.org/10.14382/epitoanyag-jsbcm.2020.19>

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Abstract

The article shows one of possible applications of the results of lineament analysis in the solution of environmental management tasks. The proposed methodology can be successfully applied to assess the mineralogical potential of the study areas regardless of the type of mineral deposit. Results can be used while planning investments by the industry of advanced materials and mining companies at the next stages of exploration. The authors have conducted a pre-processing and complex interpretation of remote sensing data in order to study the shape of individual faults and the spatial orientation of the whole network of dislocations. The final structural scheme was built in the results. The authors chose a fixed rectangular polygon within the Mongolo-Okhotsk fold belt (MOFB) as a reference area. By implementing algorithms of automated and visual methods of lineament analysis, it has been established that two groups of long-distance faults develop in the sub-latitudinal direction. Significant feature is the determination of a group of low-ranking lineaments that extend discordantly to the structure of MOFB. Identification of the form and spatial location of mapped lineament groups made it possible to identify potential areas for further detailed studies of the faults network and the spatial relationship of dislocations with mineral deposits.

Keywords: remote sensing, geophysics, geological mapping, tectonics, Mongol-Okhotsk fold belt data processing, environmental management tasks, faults, mineral deposits

Kulcsszavak: távérzékelés, geofizika, geológiai feltérképezés, tektonika, Mongol-Okhotsk vonal adatfeldvétel, környezetgazdálkodási feladatok, hibák, ásványi lerakódások

1. Introduction

One of a number of the most important factors ensuring sustainable development in the modern world is rational natural resource management. Today's industrial progress of advanced materials is provided by environmental management. Many works are devoted to the use of natural raw materials for advanced materials [1-4]. We can't say this about the methods of possible applications of the results of lineament analysis in solving environmental management problems.

The main goal of government programs in this field is increasing the country's mineral resource base through the development of new areas of interest or the reappraisal of existing deposits. To achieve this, new technologies and methods for prospecting, exploration and production of minerals are being introduced into the mining industry. The use of integrated solutions for the tasks of geological mapping and minerageny studies provides for qualitative improvement of the results.

To date, the fastest evolving method of obtaining new geological information is the processing of remote sensing data. This analysis performs during processing space images,

data from geophysical surveys and geological mapping. The main interpretation unit in the analysis process is lineament [5, 6]. The result of this work is the diagram of lineaments spatial relation. They indirectly characterize fault and blocking tectonics of the surveyed region [7, 8]. Mineral deposits connect to areas with high concentration of faulting. In this regard, the analysis of positional relation of the main fault systems in the surveyed area is of crucial importance.

There are two different approaches to conducting lineament analysis: automated (via specialized software) and visual. Both of these methods have proven effective in solving various prospecting problems [9-12]. Automated lineament analysis is excellent in regions with a simple geological structure (regular or monoclinical bedding) [13, 14]. The situation becomes more complicated if several stages of tectogenesis are evident. The results of visual lineament analysis can be considered closer to the actual geological situation, since the process implies the knowledge of geological structure and the spread of faulting patterns in the survey area. Apart from qualitative results, this kind of lineament analysis takes a lot of time and significantly slows down the processing when a large amount of geological and geophysical data is engaged.

In this regard, the most urgent task is to develop an effective method for processing remote sensing data, which would combine the results of both kinds of analysis. As the work outcome, a diagram of faulting patterns positional relation in the survey region should be developed.

To solve the tasks, authors conducted two kinds of analysis of the remote sensing data complex within the field survey site located in the tectonically active Mongol-Okhotsk fold belt (MOFB) in Russia. Within this geological structure, a large number of mineral deposits are concentrated [15].

2. A Brief History of Geological Evolution

The main structural elements of the earth's crust in surveyed region are the Aldanian Shield and the Mongol-Okhotsk folded belt (MOFB) (Fig. 1).

The history of the region geological evolution is long and extremely complex. Most scientists consider MOFB is an accretional structure as the result of collision on the southern periphery of Siberian platform. The formation of MOFB modern structure is associated with the closure of the Paleo-Asian Ocean at the end of the Cimmerian (Jurassic-Cretaceous) orogeny cycle. Results of geological investigations show that Late – Middle – Proterozoic complexes and Precambrian basement were mapped within the polygon. The dominant orientation of folded structures is sub-latitudinal.

1. ábra A vizsgált terület földrajzi elhelyezkedése és szerkezeti térképe (egyszerűsítve [16])
Jelmagyarázat: 1 - konszolidált kéreg a Mezo-Proterozoicus kezdete előtt;
2 - Tektonikus újrafeldolgozás a Korai Krétakorban; 3 - Fő hiba
Fig. 1 Geographical location and structural map of researched area (simplified from [16])
Legend: 1 – Consolidated crust by the beginning of the Meso-Proterozoic;
2 – Tectonic reworking in Early Cretaceous; 3 – Main fault

3. Methods

The total amount of work was divided into several major phases. The first phase includes the preparation of source material and the formation of a database. The geological data bank was formed via the Esri's ArcMap 10.3 software. The base materials were linked together and placed in a single coordinate system prior to input, which facilitated subsequent minimization of spatial errors when conducting lineament analysis. The work featured the following: Geological map of the Russian Federation and adjacent areas [16], Tectonic map of Northern-Central-Eastern Asia [17], Initial geophysical remote sensing data (scale 1: 500 000) courtesy of the "A. P. KARPINSKY RUSSIAN GEOLOGICAL RESEARCH INSTITUTE" (FGBU «VSEGEI») [18], Multispectral image Landsat -8 (image courtesy of the U.S. Geological Survey).

Intermediate processing of geophysical fields was carried out via Golden Software's Surfer 12 application. Horizon and full gradients were calculated; local and regional field components were distinguished. The obtained data was added sequentially to the geological data bank for further analysis.

Preliminary processing of space images was carried out via Harris Geospatial Solutions' ENVI 5.1 software. At the first phase of preparation, the Landsat 8 multispectral space image was subjected to radiometric calibration to prevent radiometric signal bias. The atmospheric correction was carried out to minimize the effect of distortion of air layer between the earth's surface and radar. The final phase in preparing a space image is the procedure for increasing the resolution of standard channels (30 m) according to the panchromatic channel (15 m) — pansharpening.

At the next phase, an automatic and visual lineament analysis of all informative layers was carried out and monomethod lineament diagrams were compiled.

The final phase was the conduct of a comprehensive interpretation of data, which includes defining the nature of lineaments mapped by remote sensing. At this phase, the verification of monomethod diagrams by comparing with each other and with other sources of information (geological and tectonic maps, diagrams, seismic origins, etc.) was of crucial significance. These procedures were performed interactively. It is imperative that the verification of monomethod diagrams include the validation of source of initial data and the lineaments obtained from it. The results of automatic analysis of geophysical data should be compared with similar resulting diagrams of visual analysis. The same is applicable to data collected from space images.

Comparison of lineament diagrams with each other was the first element in the chain of comprehensive interpretation of data aiming to remove the lineaments distinguished by one source only. The remaining lineaments were locked (grouped or merged) and transferred to a separate information layer. The diagram formed as a result of these operations was subjected to further verification using base materials and comparing with summarized and generalized tectonic maps and diagrams. The outcome was the summary diagram of lineaments positional relation in the survey area.

3.1 Automated Lineament Analysis

One of the most common methods for conducting lineament analysis is the algorithm of image “edge finding”. This algorithm is implemented in the PCI GeoAnalyst, Geomatica (LINE module) software. For this study, the LINE module of PCI Geomatica software was used. The procedure for lineaments automatic extracting consists of two phases. The first is automatic “edge finding”, i.e. search for information about areas of sharp transients in values of neighboring pixels. At the first step of processing, the radius (in pixels) of low-frequency Gaussian filter (RADI) is set to “soften” and blur the image. Next, the gradient value is set, which should be considered as a threshold value when moving to a neighboring pixel. Filtered data is analyzed for a set gradient to obtain a binary image. After analyzing the binary image, curves are extracted from it, and subsequently converted into vector graphic format by “fitting” straightened segments to them. The maximum error between the shape of these segments and original curve is set by processor. The listed parameters were set in an experimental manner for geophysical fields and space image separately (Tables 1 and 2). The result of this work was monomethod diagrams of lineaments positional relation.

Parameter	Value
RADI	10
GTHR	25
LTHR	30
FTHR	3
ATHR	45
DTHR	10

1. táblázat A LINE paraméterei a geofizikai adatokhoz
Table 1 LINE's parameters for geophysical data

Parameter	Value
RADI	3
GTHR	130
LTHR	30
FTHR	3
ATHR	45
DTHR	10

2. táblázat A LINE paraméterei a Landsat-hoz
Table 2 LINE's parameters for Landsat

3.2 The Results of Automated Lineament Analysis

High informative results were received by geophysical data processing. (Fig. 2). Lineaments have a predominantly sub-latitudinal and SW-NE spatial orientation. Analysis of other materials of geophysical fields and its transformants indicates that the mapped lineaments have a similar spatial orientation. Their largest number is evident in the southern part of the site. There they form chains stretching in the sub-latitudinal direction. These conclusions are confirmed by rose diagrams and lineament density calculations.

2. ábra Az automatizált lineáris elemzés (LINE) eredményei. Csak az 1000 métert meghaladó vonalak. A - mágneses mező anomáliái; B - a vonalak térbeli sűrűsége; C - Rose plot

Fig. 2 Results of the automated lineament analysis (LINE). There are only lineaments longer 1000 meters. A – anomaly magnetic field; B – Spatial density of lineaments; C – Rose plot

The least informative were the results of the gravity field automated analysis. This can be explained by the absence of intense anomalies and the smooth variation of field over a large area.

The lineament diagram of a space image differs significantly from the rest. Here it is difficult to trace one predominant direction of the lineament strike, but several can be distinguished: WSW, NNE, ENE. An analysis of density plot indicates that the concentration of lineaments is evident in the southern and northwestern parts of the site, which partially correlates with the results of processing data from geophysical fields (Fig. 3).

While analyzing the overall picture of the lineament’s positional relation, it can be noted that there are both similar and distinctive features. The predominant sub-latitudinal strike of lineaments and their increased concentration in the southern part of the site were identified.

3. ábra Az automatizált lineáris elemzés (LINE) eredményei. Csak az 1000 métert meghaladó vonalak. A - LANDSAT 8 (5. sáv); B - a vonalak térbeli sűrűsége; C - Rose plot

Fig. 3 Results of the automated lineament analysis (LINE). There are only lineaments longer 1000 meters. A – LANDSAT 8 (Band 5); B – Spatial density of lineaments; C – Rose plot

3.3 Visual Lineament Analysis

The main requirement for the process of conducting visual lineament analysis was to maintain a strict spatial reference. In this regard, the ArcMap 10.5 and Corel Draw X9 (with the coordinate grid set) software was used. Lineaments were distinguished via direct decryption method for all data types. The following was considered the signs of lineaments on geophysical fields and transformants:

- Changes in color and tone characteristics of the field
- Areas of high field gradients
- A sharp transient in direction of neighboring isometric curves, as well as their interruption

It should be noted that this approach enables ranking the distinguished lineaments while processing. The first two signs correspond to long and large lineaments, which can be interpreted as regional faults. In addition to a large extent, they are characterized by high contrast of display in the fields. The third sign makes it possible to map segments of significantly lesser extent and contrast of display. Such lineaments are considered local faulting (Fig. 4).

4. ábra A vizuális vonal-elemzés eredményei. A - mágneses mező anomália: 1 - 1. rangú vonalak, 2 - 2. rangú vonalak; B - a vonalak térbeli sűrűsége; C - Rose plot
Fig. 4 Results of the visual lineament analysis. A - Anomaly magnetic field: 1 - 1st rank lineaments, 2 - 2nd rank lineaments; B - Spatial density of lineaments; C - Rose plot

3.4 Results of Visual Analysis

A similar picture of lineaments' positional relation is observed in all monomethod lineament diagrams whose sources were geophysical fields and transformants. General sub-latitudinal strike is evident. A group of lineaments of SW-NE strike stands out in the northwestern part of surveying panel. The number of lineaments per area unit is approximately the same throughout the site with a slight increase in the southern part.

The signs of lineaments in the space image were natural straightened land forms, including riverbeds, mountain ranges, long narrow basins. The initial multispectral image in a combination of 7, 4, and 2 channels was selected for analysis (Fig. 5). This combination of channels, as was shown by researchers, is the most informative when mapping lineaments that could be interpreted as faulting [19, 20]. Further, lineaments were divided into two ranks.

5. ábra A vizuális vonal-elemzés eredményei. A - LANDSAT 8 (7,4,2 sávok): 1 - 1. rangsor vonalak, 2 - 2. rangsor vonalak; B - a vonalak térbeli sűrűsége; C-1 - Rose plot az 1. rang; C-2 - Rose plot a 2. rang
Fig. 5 Results of the visual lineament analysis. A - LANDSAT 8 (7,4,2 bands): 1 - 1st rank lineaments, 2 - 2nd rank lineaments; B - Spatial density of lineaments; C-1 - Rose plot for 1st rank lineaments; C-2 - Rose plot for 2nd rank lineaments

The positional relation pattern of lineaments according to space image differs from the results of the same analysis of geophysical fields and transformants. Lineaments of the 1st and 2nd ranks are characterized by different orientations. The primary strike of the 1st rank lineaments is the NW direction. This can be explained by the general orientation of river system in this area. It is difficult to identify the general strike for the 2nd rank lineaments, since they are approximately equally distributed between the SE and SW directions. This fact is of great interest and the need for further research, since there are no significant differences in the spatial orientation of lineaments according to remote geophysical survey. An increased number of straightened land sections per area unit is observed in the SE and NE parts of the site.

3.5 Comprehensive Interpretation and Summary Diagram

At the final phase, a comprehensive interpretation of the obtained data was carried out and a diagram was developed reflecting the positional relation of primary and secondary lineaments in the survey area (Fig. 6).

6. ábra A kapott vonalrendszer. Jelmagyarázat: 1 - konszolidált kéreg a Meso-Proterozoicus kezdete előtt; 2 - Tektonikus újrafeldolgozás a Korai Krétakorban; 3 - 3a - 1. rangú vonás, 3b - 2. rangú vonás
Fig. 6 Resulting scheme of lineaments. Legend: 1 - Consolidated crust by the beginning of the Meso-Proterozoic; 2 - Tectonic reworking in Early Cretaceous; 3 - Lineaments: 3a - 1st rank lineament, 3b - 2nd rank lineaments

Based on the results of summary diagram analysis, several groups of lineaments were distinguished that strike generally in the sub-latitudinal direction. The northern group was mapped along

the area of development of the deep fault, which is the structural boundary between MOFB and the Aldanian Shield. It should be noted that according to the results of interpretation there was not distinguished any single fault structure, but the extended fragments (up to 5,000 m) oriented in the adjacent axe were mapped. The southern group of lineaments is represented by extended (up to 4000 m) faults. An interesting feature is the presence of a group of 2nd rank lineaments, the strike of which (NW-SE) radically differs from other groups of faulting. The authors suggest that the faults of this group can be parts of the general deep faults and may spatially connect the southern and northern branches of rifting, thereby combining them into a single faulting pattern.

4. Conclusions

Thus, the summary diagram of positional relation of faulting in the survey area results the comprehensive method of remote sensing data processing and interpretation. Two general faulting groups with a sublatitudinal orientation were distinguished. No single for general fault structure was registered, but several faults of the same rank were distinguished within these groups. An important feature of the summary diagram is the presence of a group of 2nd rank faults with NW-SE strike, located between the general rifting groups.

The results obtained indicate that the most promising areas for prospecting and exploration for mineral deposits are the southern and northern fault propagation groups distinguished in the course of work. In addition, the area of propagation of 2nd rank faulting patterns is also of heightened interest.

Acknowledgements

The publication has been prepared in the context of a government order of Russia on «Development of interdisciplinary trends in the complex development of the Earth's interior and nature preservation» # 075-03-2020-127\1.

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Ref.:

Ageev, Aleksey S. – Gömze, László A. – Kotov, Oleg L.: *Results of processing and complex interpretation of geophysical and satellite remote sensing data in the context of environmental management tasks* *Építőanyag – Journal of Silicate Based and Composite Materials*, Vol. 72, No. 4 (2020), 118–122. p. <https://doi.org/10.14382/epitoanyag-jsbcm.2020.19>