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GIS-Practical Experience in the Boundaries Definition of the Platform Deep Crustal Blocks on the Studying of the Earth's Surface Fractal Divisibility: Example of the White Sea-Kuloi Plateau

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Abstract: This study examines the use of the geographic information systems (GIS) in structural geomorphology to build the model of the crust based on fractal analysis of relief. Fractal theory, developed by B. Mandelbrot, used to determination morpho-bloc divisibility of the Earth's surface. There is the traceable statistically recurring relief structure indicate the appropriate tiered hierarchy of crustal blocks forming the tectonic and kinematic layers. This hypothesis tested on a digital elevation model (DEM) of the White Sea-Kuloi Plateau — an area of tectonic and magmatic activity of the Paleozoic era. Found the correlation of position the kimberlite magmatic bodies with the tectonic blocks certain depth according to a fractal analysis.

Key words: Structural relief, tectonic blocs, geographic information systems, digital elevation model, fractal dimension.

1. Introduction

At present days structural geomorphology defines surface earth objects, "not daring" to look into the depths of the earth. Geomorphology "given" this opportunity to geophysical sciences. To the XXI century, this "imbalance" in the study of deep structures began to "straighten out" due to tectonic and geodynamics research [1, 7, 9, 11]. It is known fact for any geomorphologist that the Earth's surface is the direct (!) sign of the crustal structures. Geomety of one face of tectonic blocks peculiar mosaic manifested in relief that allows you directly to read information about the properties of tectonic blocks. Nevertheless, still in geology it prevalent of distorted understanding of the systemic connections in the lithosphere — there is strong opinion about the isolation and independence of the existence of tectonic faults as the geological bodies. This study based on the following position: tectonic fault is the boundary between certain moving volumes of the lithosphere, and, like in any boundary zone in spatial development, it is the tectonic movement of the aggregate volumes of rocks or its geometry; tectonic faults, in most cases, expression on the Earth surface as a drainage network. These suppositions were decided to examine for the White Sea-Kuloi plateau. This region is found at the north-east of the East-European plain. Study area is about 24 000 km^2 — Fig. 1. From the most geomorphological positions the area is a structural denudational plateau, low hill plains. There are V-forms of the river valleys and high drainage density. The well marked river terrace is covered with low thickness of quarternary deposits. All this indicates about ascending tectonic of the territory.

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2. Theoretical Principles

About connections of discrete surface areas with tectonic structure wrote geomorphologist V. P. Philosofov. On the basis of this objective relation, he has developed a superior method for the studying neotectonic structures [6]. However, this method is based on the contour models without automated computational processes and inherently very laborious. It gives a qualitative description of tectonic processes, this method does not provide the quantitative aspect of tectonic events (depth of faulting). Whereas quantitative tectonic movement is determined at the present by the geometry of the moving objects. It means stochastic ties of the block forms with the depth of the contour tectonic boundaries (surface area to volume units).

Fig. 1 Studied area — White Sea-Kuloy plateau (red rectangle).

We are encouraged of one V. P. Filosofov's conclusion that exist direct relations surfaces of the watersheds (or their aggregations) with the tectonic crustal blocks. That helps to study the hierarchical rank-block structure of the crust and its quantitative characteristics.

In the defining of the fractal measure boundaries of the morfo-block are used the relationship between perimeter and area of a fractal object proposed by the mathematician B. Mandelbrot [10]:

$$P^{1/d} = k_1 S^{1/2} \quad (1)$$

where *P, S* – perimeter and area of the object respectively, *d* – fractal dimension, *k1* – coupling coefficient.

The transition from the square to the depth of the penetration tectonic border (to volume *V*) is based on empirical observations of the Earth layers (characteristic coefficient k_2) [3] and the concept of auto-model geodynamic processes [1, 13] or the fractal divisibility Earth crust [8, 10]:

$$k_1 S^{1/2} = k_2 V^{1/3} \quad (2)$$

3. Results

In the research processing it was allocated multilevel blocks. We used modern methods for the geoprocessing DEM [4, 5, 14, 15] of the large watershed — between the rivers of the Northern Dvina and Mezen. As mentioned, the energy measure of the

tectonic forces or destruction in the boundary zones is associated with penetration depth of tectonic boundaries adopted from fractal geometry [10]. Nonlinearity boundaries of the tectonic blocks appeared from the watershed surfaces and its aggregations — morpho-blocks. This is done through DEM with standard hydrology GIS-module [4]. In this way revealed three levels of hierarchy (truncated volumes) of the respective blocks — Fig. 2. On the basis of the values of fractal measures (f.1) we received block boundaries to calculate of the earth crust model of the White Sea-Kuloi plateau to a depth of 1.2-6.8 km (f.2) – Fig. 3. Spatial correlation was done up for the known magma signs and reducing depth of tectonic blocs and fracturing zones on the territory from calculated data — Fig. 4. The process of the study revealed the following: the fractal dimension of the blocks surface of the White Sea-Kuloi plateau is 1.09-1.16.

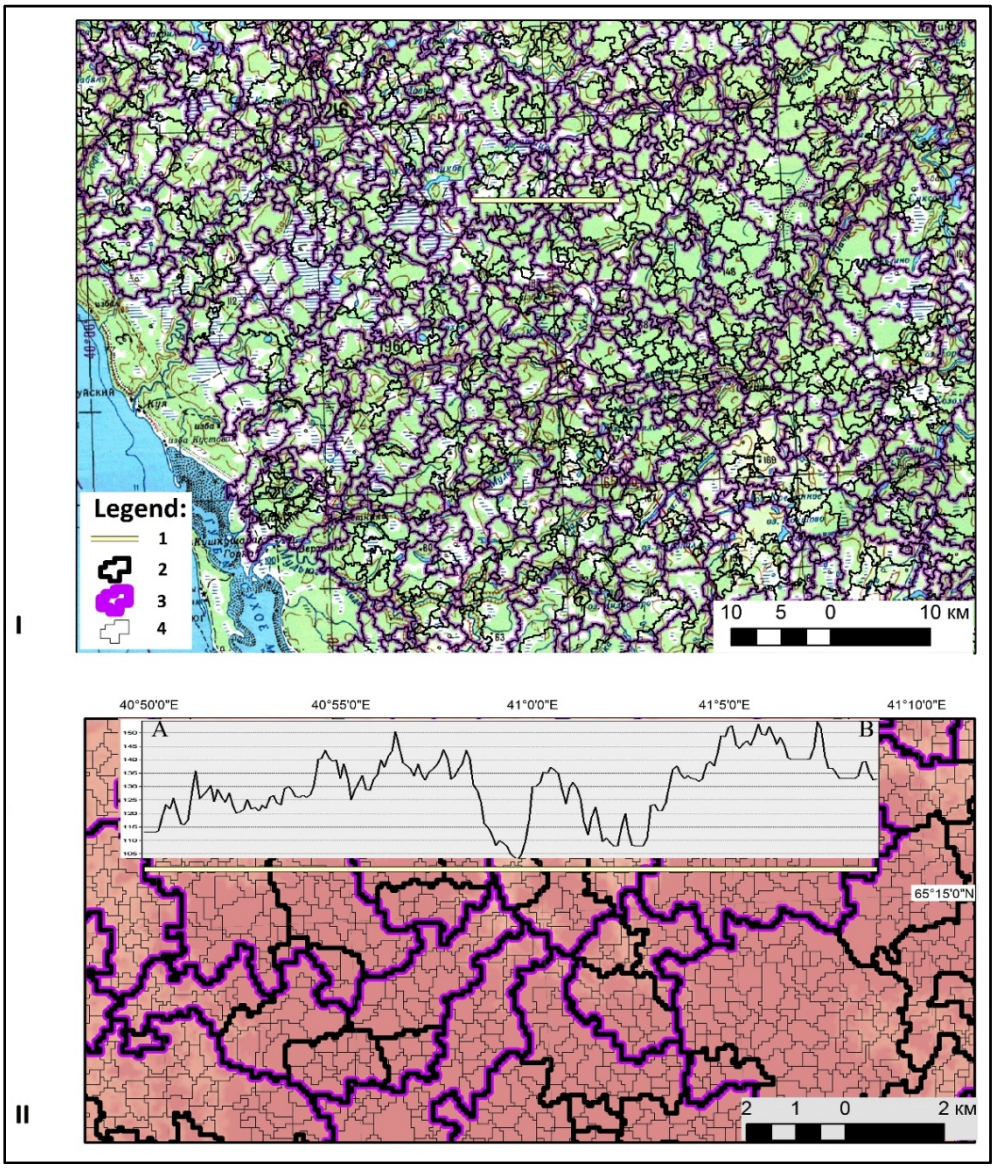

Fig. 2 The blocs allocation of the White Sea-Kuloi plateau and the principle of its receipt as shown in the example of the profile of the earth's surface A-B (in the lower part of the figure - increased). Numbers in legend part I: 1 – profile AB, 2 – morpho-blocs of the second aggregation, 3 - morpho-blocs of the third aggregation, 4 - morpho-blocs of the first aggregation; part II: AB profile and intersect them morpho-blocs (increased).

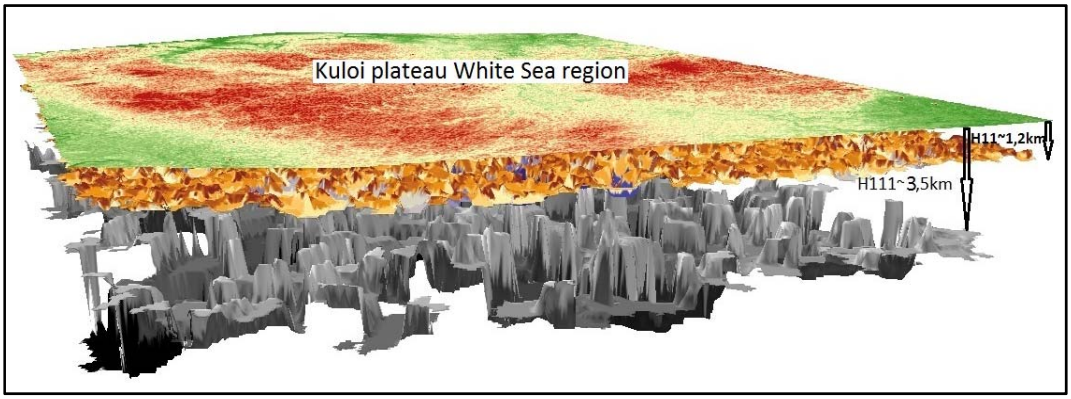

Fig. 3 Two level blocks divisibility of the crustal – H11 and H111, according to fractal analysis of the study areas (a perspective view, the arrows show the average power of the tectonic blocks).

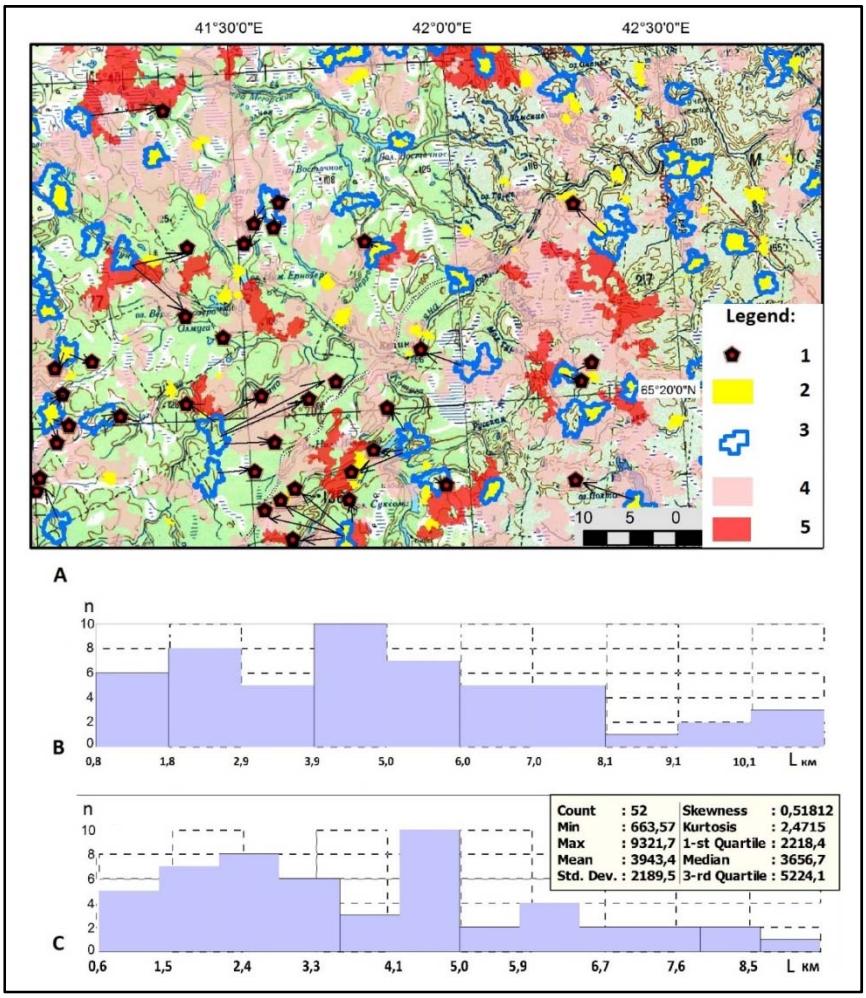

Fig. 4 Zones of the convergence of the calculated depth of the layers and zones of high permeability (fractures) of Earth's crust according to fractal analysis. The position of magma chambers (low depth of the blocks) and known closely to surface kimberlite bodies for the study area. The arrows indicate the relationship with kimberlite formations and magmatic columns at depths 1.6-2.6km interpreted according to the fractal analysis. The length of the arrow is about 0-4km. Numbers in legend are – part A: 1 – known magmatic formations, 2 - zones of the convergence level H11 and H111, 3 – blocs level H111 of low thickness, 4 – zones of medium crustal permeability, 5 – zones of high crustal permeability; part B: the histogram of distant of the low thickness blocs (1.6-2.6 km) to the numbers of the surface magmatic formations; part C: the histogram of distant of the zones of the convergence level H11 and H111 to the numbers of the surface magmatic formations.

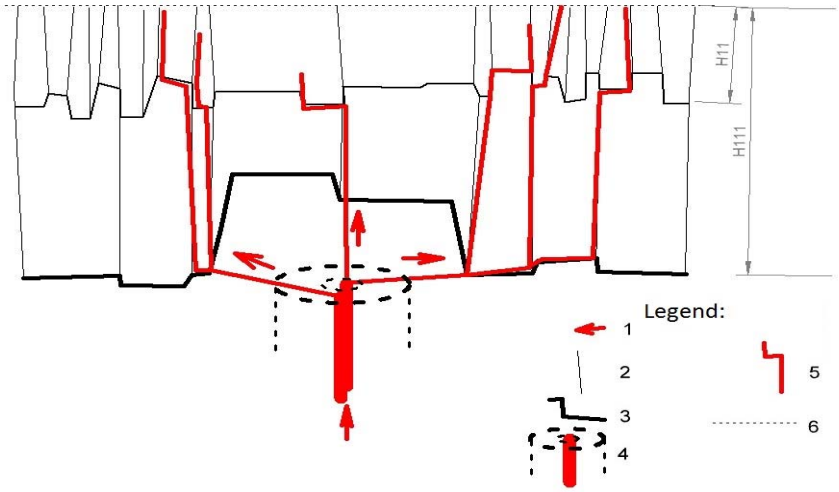

Fig. 5 Diagram of the vertical kimberlite field and block structure in the crust according to fractal analysis. Numbers: 1 – direction of movement of magma in the geological past; 2 – subvertical weakened zones - border of blocks; 3 – the tectonic block soles, corresponding to the depth of the 2-nd and 3-rd bloc levels; 4 – magma columns and its area of influence; 5 – dikes; 6 – day surface.

This corresponds to a geometric divisibility blocks 3.2-3.8, identified in the late 80-ies XX by M.A. Sadovsky, based on observations and laboratory experiments — the coefficient of the rocks and lithospheric blocs divisibility equal to an average of 3.5 [13]. On this data and calculating depth model it has been proposed about the possible penetration of magmatic melts on the interblock zones in the Paleozoic era. On the Fig. 5, it proposed scheme of the structure and position of the magma-fluid columns field on the basis of the done calculations of the penetration depth of tectonic block boundaries. In general, it corresponds to models derived from geophysical data. For example, the N. A. Prusakova determined [12, p. 22]: "At the top of the density section trans-crustal integrated density in homogeneities are spatially associated with the White Sea shore kimberlite fields, are isolated objects with elevated by density and magnetic characteristics and displaying complex anomalies of the gravitational and magnetic fields. The latter are characterized by a combination of local maximums Δg and ΔT that apparently allows to link them to the nature of buried (at a depth of 2-4 km) units mafic-ultramafic magmatism. Most of the manifestations of magmatism the White Sea shore kimberlite fields localized (in groups) within and on the periphery of the contours of the magmatic areas" (emphasis in bold and translate by I. S. Sergeev). The diagram of the structure of kimberlite magmatism manifestations areas to a depth of 3.5 km obtained according to the fractal analysis presented in Fig. 5. As one can see in this figure the scheme is confirmed by cited above N. A. Prusakova's conclusions of obtained in the analysis of geological and geophysical data on the study area.

4. Conclusions

The developed method of the fractal analysis of the Earth's surface divisibility allows to trace the depth development of the interblock tectonic boundaries. The method bases on the following important principles:

(1) Acting "participants" are manifestations of endogenous forces are blocks — this is local volumes of the lithosphere are contacting with each other through the perimeter boundary which are quasi-vertical faults at the surface manifested as parts surfaces watersheds (or their aggregates, so-called morpho-blocks);

(2) The ratio of the volume and surface area of tectonic block (to a first approximation) connect with fractal measure — the degree of expression of tectonic energy of crushing blocks on the boundaries (similar to

the coefficient of the lithospheric auto-model divisibility investigated by M. A. Sadovsky).

These provisions applied to the digital elevation model using mathematical apparatus of GIS allows to consider the tectonic structure of the platform regions in the practical aspect of identifying the spatial position of magmatic formation in Paleozoic strata.

References

[1] Adamovich, A. N., Levi, K. G., and Sankov, V. A. 1986. "Some Regularities of the Block Lithospheric: Quantitative Analysis of Geological Phenomena." Irkutsk 1: 22-32.

[2] Astafev B., Bogdanov, Yu., Yu, B., Voinova, O. A., and Voinov, A. S. 2012. State Geological Map of the Russian Federation. Scale 1: 1 000 000. A series of Baltic. Sheet Q-37-Arkhangelsk. Saint Petersburg, p. 302.

[3] The Electronic Atlas. 2013. "Support Geological and Geophysical Profiles of Russia." Seismic profiles of the deep researches in the period from 1972 to 1995. Russian research institute of geology of A. Karpinsky. Saint Petersburg.

[4] Electronic resource of Environmental Systems Research Institute (ESRI): http://resources.arcgis.com/ru/help/. Treatment Date: 12/12/2015.

[5] Etzelmuller, B. 2009. "Structuring the Digital Elevation Model into Landform Elements through Watershed Segmentation of Curvature." In: Proceedings of Geomorphometry, University of Zurich, Zurich, Switzerland, 31 August 2009, pp. 55-60.

[6] Filosofov, V. P. 1975. The search of the Tectonic Structures with Morphometric Method. Vostriakov A. V. Saratov (Ed.). p. 233.

[7] Gendler, V. E., Belkina, I. L., Berendeev, N. S., and Gershanik, S. Ju. 1986. "The Use of Satellite Data for the Study of Deep Crustal Structure of Karelian-Kola Region." Block Tectonics and Ore-Bearing Prospects of the Northwest Russian Platform. Saint Petersburg, pp. 52-62.

[8] Goriyanov, P. M., and Ivanyuk, G. Yu. 2001. "Power Percolation — Resource for New Ideas in Geotectonics." Bulletin of Voronezh State University11: 7-22.

[9] Levi, K. G. 2014. "Geodynamic Activity of the Lithosphere and Problems of Tectonophysics — Outlook after 35 Years." Geodynamics & Tectonophysics 5 (2): 527-46.

[10] Mandelbrot B. 2002. Fractal Geometry of Nature. Transl. from English. Logunov A. R., Moscow, p. 664.

[11] Nur, A. 1982. "The Origin of Tensile Fracture Lineaments". J. Structure Geology 4 (1) 31-40.

[12] Prusakova, N. A. 2004. "Geological and Geophysical Search Model of White Sea Kuloi plateau kimberlite Field." Abstract of the Thesis for the Degree of Geological-Mineralogical Sciences, Moscow, p. 28.

[13] Sadovskij, M. A. 1986. "Self-similarity of the Geodynamic Processes." Herald of the Academy of Sciences of the USSR 8: 3-11.

[14] Sergeev, I. S., and Egorov, I. V. 2015. "Structural Geomorphology of the White Sea Region with Fractal Geometry in GIS Environment." In: Proceedings of the Russian Geographical Society 4 (147): 24-38.

[15] Electronic Resource of the U.S. Geological Survey: http://earthexplorer.usgs.gov/. Treatment Date: 12.10.2015.