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Computer detection of the Earth's crust blocks using satellite image lineaments

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SUMMARY

Multidirectional orthogonal lineament systems are boundaries of the Earth’s crust block structures and appear on satellite images as areas with different brightness and texture. This peculiarity allows to detect boundaries of individual blocks and analyze the complex mosaic-block structure of territories using lineament analysis methods. A computer technique of satellite image lineament analysis is proposed and is aimed at detecting the Earth's crust blocks. It is based on minimizing the brightness heterogeneity within individual blocks, bounded by the minimum number of multidirectional lineaments and their systems. The methodology was applied for detecting block structures withing a number of the Earth's crust remote locations – fragments of Scotland, Norway, the Caucasus, the East African Rift, the Alps, Pyrenees, Carpathians, the Ural Mountains territories, etc. using Landsat-8 images. As a result it was found that lineament systems with azimuths of 45-135 and 22.5-112.5 degrees are present in all study areas; lineament systems with azimuths of 60-150 and 75-165 degrees and also networks without an orthogonal pair were also identified for some areas. The results of the Earth's crust blocks detection are consistent with geological maps and correspond to the results of geodynamic modeling based on seismic and geological data.

Introduction

The block divisibility is essential and inalienable attribute of the Earth's crust (Archegov, 2012). According to experience of many geoscientists, block structure of the most diverse parts of the Earth's crust is controlled by several systems of orthogonal lineaments (Busygin and Nikulin, 2016; Busygin et al., 2019-1). There are from two to four such systems, and only in rare cases there are more of them. Lineaments are often boundaries of individual blocks. Each block, being relatively independent from neighbouring blocks is subjected to vertical movements with its own frequency and amplitude characteristics. As a result, the Earth's crust blocks are subjected to denudation, peneplanation and weathering processes in varying degrees, which in turn increases the differences in blocks behaviour with horizontal movements. These factors together lead to forming distinct landscapes within separate blocks. They are represented on satellite images as sites with similar brightness or texture (regularly repeating pattern). For this reason, it is possible to study the territories block structure from satellite images using lineament analysis methods. In this case, not only lineaments themselves are analysed, but also the surface areas bounded by them.

When analysing the shape of allocated blocks, it is important to take into account the fact that each individual orthogonal lineament system forms rectangular blocks, but the second system, rotated by a certain angle relative to the first and shifted in a horizontal plane, creates a more complex mosaic-block pattern. Since there are usually more of such systems, they generate a set of polygons of various sizes and shapes (Figure 1). This provides a complexity, differentiation and variability of the earth's surface observed on satellite images.

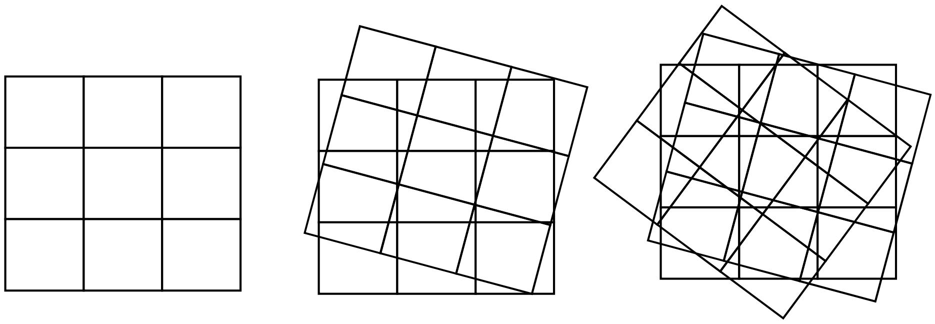

Figure 1 *The results of combining one, two and three orthogonal lineament systems*

The objective is creating a computer methodology for detecting boundaries of the Earth’s crust blocks by means of analyzing texture and brightness characteristics of surface areas bounded by multidirectional lineaments on satellite images.

Methods of investigation

The study of block structure at the moment cannot be performed in a fully automatic mode due to the task complexity and a huge variety of real geological conditions. This circumstance reduces the task of the methodology automation to automation of its individual stages, requiring large amounts of computation. The role of the expert-interpreter consists in determining the initial parameters of lineament systems, selecting criteria for blocks heterogeneity, controlling the intermediate results and several other procedures.

The task was to detect the Earth's crust block system G formed by a number of rectilinear lineament systems F bounding the Earth's crust blocks in such a way as to minimize the total heterogeneity of satellite image brightness inside individual blocks given that the number of them is minimal:

$$G = \bigcup_{i=1}^{m} F_i(n, D) \;\Big|\; n \to min,\; D \to min\,, \quad (1)$$

where
m – number of orthogonal lineament systems;

n – number of lineaments;
k – number of blocks formed by lineaments;
$D = \sum_{j=1}^{k} d_j$ – total brightness heterogeneity;
d – measure of brightness heterogeneity within a block.

The requirement to minimize the number of blocks is crucial, since it allows to exclude from consideration insignificant blocks of higher levels. Since the lithosphere is divisible up to meter-sized objects, ignoring such a requirement would lead to an almost unlimited complication of the problem without any obvious practical sense. The requirement to minimize the number of orthogonal lineament systems is intended to take into account the experience of numerous researchers who have come to the conclusion about a limited number of them, their continuity in strike, and a certain equidistance (alternation at approximately the same intervals).

The computational complexity of this problem is extremely high and requires expert opinion to narrow the search for acceptable solutions.

Another problem is choosing a measure of brightness homogeneity inside blocks. Such a common metric as dispersion, which allows to get good results for most types of landscapes, in some cases is unacceptable. In this view, for some blocks the brightness homogeneity was estimated using some texture characteristics, fractal dimension, distribution characteristics of contrasting brightness borders and cluster analysis results (Busygin et al., 2017). An expert chooses a specific measure for individual sites.

The azimuth of the first orthogonal lineament system corresponds to the azimuth of the largest, the most pronounced and continuous in strike element of landscape, taken as the base. The azimuths of the second and subsequent systems are determined in a similar way (Figure 2). At the same time, the necessity of using an additional system is based on the functional (1) minimization requirements.

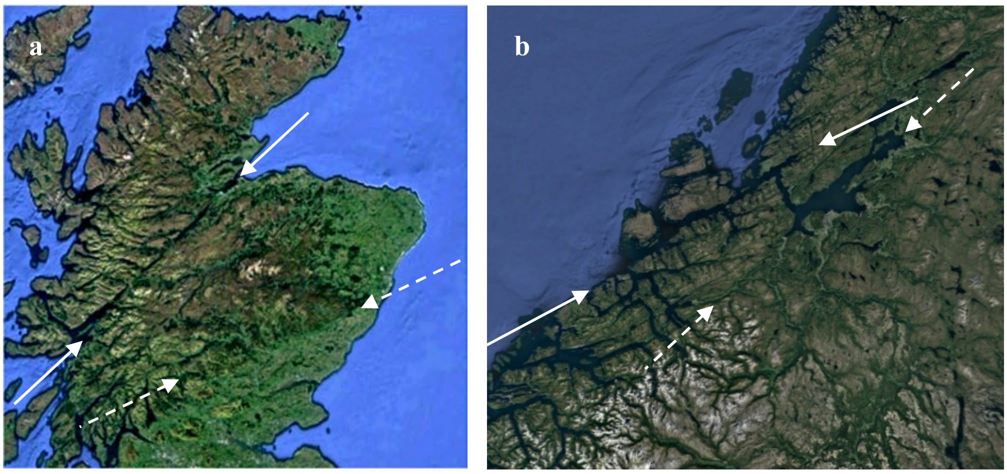

Figure 2 *Selection the azimuths of lineament systems: the basic elements of the first and second systems (solid and dashed arrows, respectively) on the example of Scotland (a) and Norway (b) study areas*

The work was implemented using a specialized geoinformation system RAPID (Busygin et al., 2019-2).

Results and discussion

The methodology represented above was applied on several Earth's crust sites, located on a thousand of kilometers distant from each other (Scotland, Norway, the Caucasus, East African Rift, Alps, Pyrenees, Carpathians, Ural Mountains, etc.). The single bands of Landsat-8 images, as well as their syntheses were analyzed. Some preliminary research results are represented below. In Figure 3 only a few sites are presented, but conclusions are drawn based on all studied areas.

The following important points should be noted.

1. Despite the remote location, and significantly different geological conditions of different study areas, several orthogonal lineament systems are presented there – with azimuths of 45-135° and 22.5-112.5°. They were also detected by other researchers in areas that are significantly different in their geological structure and landscape (Wang et al., 2017; Vorobieva et al., 2017). In addition, systems with azimuths of 60–150° and 75–165° were identified on the most of study areas. In some areas, identified systems are specific only to them (for example, the azimuth of lineament network in Norway is 7° and it does not have an orthogonal pair).

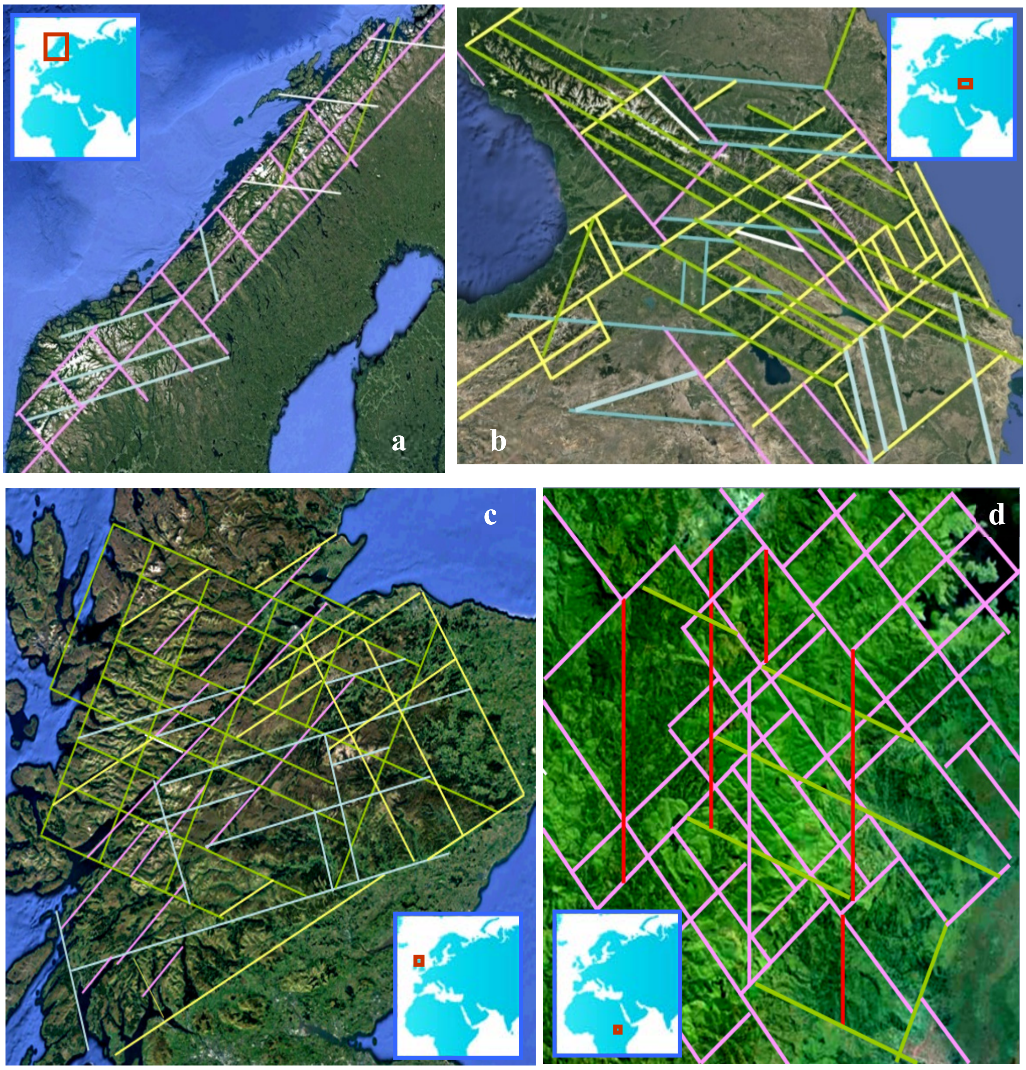

Figure 3 *The results of detecting boundaries of the Earth's crust blocks on the example of Norway (a), the Caucasus (b), Scotland (c), and East African Rift (d) study areas. The colour of lineaments corresponds to their azimuths*

2. The combination of the identified blocks with geological maps of appropriate scales allows to conclude about their sufficient consistency (Figure 4).

As shown in Figure 4, several linear structures do not appear on existing maps, although they are clearly shown up on images. There is also significant proximity of the selected blocks to the results of modern geodynamic modelling from seismic and geological data (Soloviev and Gorshkov, 2017). This phenomenon has long been known to specialists and it is one of the factors that add value to Earth exploration from space.

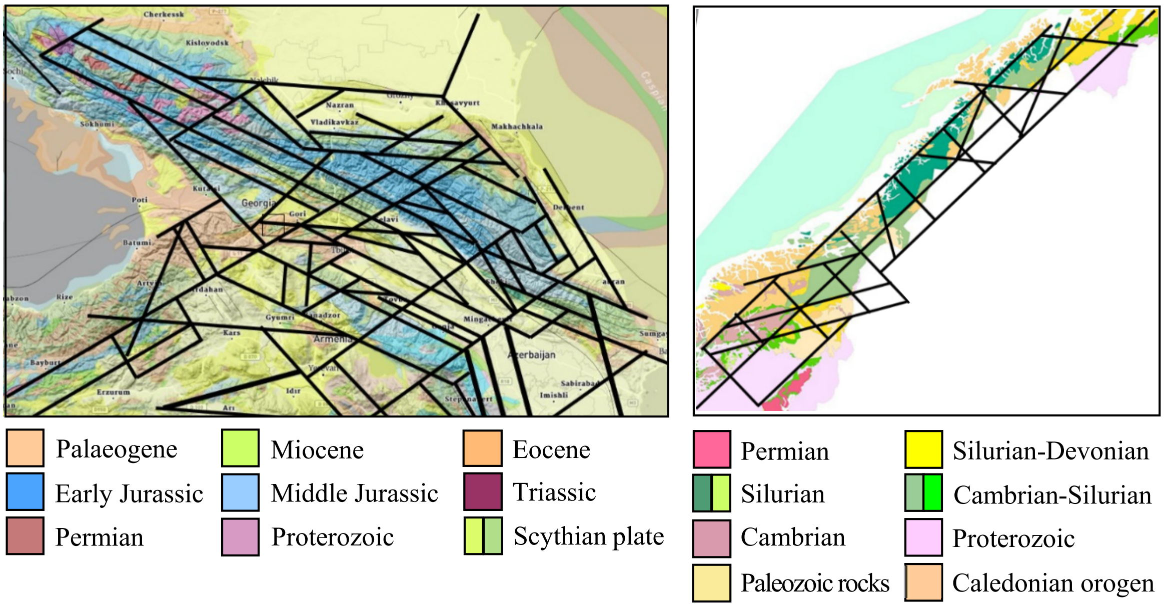

Figure 4 *Combination of detected blocks with geological maps of the Caucasus (according to macrostrat.org) and Norway (according to the Norwegian Geological Survey data)*

Conclusions

The boundaries of all the studied mountain regions, regardless of their spatial configuration, can be approximated by a set of blocks formed by several orthogonal lineament systems. The development of this work is aimed at reducing the subjective component and increase the degree of automation; the development and/or finding of more perfect measures of landscape uniformity calculated based on the brightness values of satellite images. In addition to the polygonal blocks studied in this paper, the Earth's crust is composed of blocks with some faces formed by circular structures. Determining their influence is the goal of separate studies and has not been considered here.

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