Using a digital relief model for searching for primary sources of gold in metamorphic complexes of the Evota region (Aldan-Stanovoy shield, North-Asian craton)

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Abstract. Placers of precious metals and other mineral resources are associated with the uplifted basement of the North-Asian craton and metamorphic terrains near its borders. The complex geological structure of these territories does not allow to make obvious conclusions about the sources of the placers. One of the areas of the southern outcrop of the craton basement, the Evota gold-bearing region of the Aldan-Stanovoy shield was studied. Analysis of the morphology of native gold selected from creeks of the region and eluvium from one of the primary deposits show that grains with similar morphological features occur. Probably, not far from the points of sampling, primary sources are located. Possible erosion and sediment removal should occur in positive forms of relief. Therefore, an attempt to determine the location of primary sources by modeling positive forms of relief, where erosion occurs and removal could be manifested, was made. The methodology for modeling these forms using modern geoinformation systems was considered as an attempt to analyze the obtained results. Digitized relief maps (topographic base) of the area and sample points with discovered gold were a basis for the calculations. Further steps were: building a surface of relief as a regular network of highs, calculating directions and slope angle of the surface, building a map of removal vectors, constructing a path with a maximum slope upward from the point with gold particles discover. Lines of positive forms of relief confined to gold discover points were constructed as a result. Field works for identifying signs of gold content in these lines and point sampling of rock debris were carried out. Microprobe analyses of rock debris were performed. Minerals of gold and silver were discovered in the debris. The obtained data shows that this method of analysis can be useful for deciphering ore-bearing structures and searching for primary sources.

1. Introduction

In the south of the North-Asian craton within the Aldan-Stanovoy shield, in gold-bearing placers, platinum-sperrylite associations are widely spread and few diamond crystals are discovered [1-3]. The prospecting of primary sources of these minerals is an urgent task even till now. Due to discoveries of autochthonous placer gold, an attempt to carry out geomorphological analysis of the territory using modern geoinformation technologies was made in this work. One of the significant advantages of geographic information system (GIS) technologies over regular "paper" cartographic research methods are able to create spatial models in three dimensions with a large amount of data and to operate with height marks [4]. Calculations performed using software algorithms are considered objective. In this
relation, a digital relief model was built and analyzed. According to [5] surface washout alone can only create concave slopes. Profiles of a different form occur when erosion was involved in the formation process. Since erosion is a limited and variable process in time and space, and surface washout, on the contrary, is in effect everywhere and almost continuously, on the earth's surface, concave profiles of slopes prevail [5]. The used method allows us to identify convex relief forms. These forms, on the one hand, are a provenance area of the debris; on the other hand, they are characterized by the least amount of sedimentary deposits overlying the bedrock. It is good for primary source prospecting.

2. Geological setting
The territory considered in the article is located in the southern North-Asian craton, the northern part of the Evota gold-bearing area of the Aldan-Stanovoy shield [6, 7]. Outcrops of the Precambrian metamorphic complexes and Mesozoic syenites are exposed to the territory. Mapping and prospecting operations within the studied territory were repeatedly performed by various organizations. As a result, numerous points of mineralization and placers of gold, as well as primary gold deposits were discovered. All these objects are combined into cluster, called the Leglier ore cluster. Several types of primary gold mineralization: 1) Precambrian in crystalline schists; 2) Mesozoic associated with syenite intrusions were identified by predecessors. The second type has no commercial significance. We sampled gold from eluvial deposits at the territory of one gold deposit (in crystalline schists) at P. Pinigin deposit (figure 1) [8]. The specific feature of this gold presence of large amounts of planes due to forming in schistose rocks was established (figure 1, grain A). During panning alluvial sediments in various points of considered area slightly modified angular with flat faces gold particles in addition to widely spread well-rounded gold grains were found (figure 1, rest of the grains). The presence of such gold may indicate the closeness of primary sources.

Figure 1. Scheme of outcrops of syenites and schists with heavy concentrate sampling points which contain gold particles with flat surfaces. A shadow relief model as a background was used, which shows distinct manifestation of outcrops of igneous rocks by positive relief forms. The scheme is based on the materials of "Yakutskgeologiya" JSC. 1 - syenites, 2 – crystalline schists, 3 – rivers, 4 - alluvial Au flows, 5 - Au deposits, 6 - lumps of rocks with Au or Ag content, 7 - heavy concentrate sampling points and corresponding microphotos of native gold (A-G – areas: A - P. Pinigin deposit, B
– Korot, C - Ulahan-Leglier, D - Eloviy, E - Maliy Nimnir, F - Medvedevka, G – Mikhailovka). White stripe on microphotos - 100 µm.

3. Research methods

Igneous rocks, which in our case are associated with gold, usually form positive relief forms [9]. Such forms were mapped, using the method described below, from points where gold was previously discovered.

This task using the ArcGIS software and the ArcGIS "Spatial Analyst" module was solved. Additionally, the "Model Builder" module was used. A digitized map (topographic base) of relief of the area with marked sampling points, where the gold was found according to the results of laboratory research, was taken as the basis. Building the surface of relief using "Topo in raster" tool in the form of a grid with a cell size 10 by 10 meters was the next step. For determining the direction of removal in each cell the "Aspect" tool was used. Gradients of changes of the slope surface (angle of gradient) were calculated using the "Slope" tool.

A new surface (grid) with the calculated slope direction for all cells of the input surface (in this case, surface of relief) was created with the "Aspect" tool, passing over it with a sliding window in n on n cells and calculating a plane with a Z-value for the central cell. The direction of the faces of this plane was the aspect of the central cell. The direction clockwise in degrees from 0 (North) to 360 (North) was measured, passing a full circle. The value -1 for flat areas that do not have a direction downward the slope was set. The "Slope" tool allows calculating the gradient (value of angle of the gradient), or the rate of maximum change of Z value between a specific cell and neighboring cells of the input raster (surface of relief).

The calculation algorithm is similar to the one in the "Aspect" tool used. For each grid cell, a plane for Z-values from the neighborhood n on n cells was calculated. The slope value of this plane was calculated using the average maximum method. For the management of detailing of received directions, the input grid (surface of relief) was generalized by applying the "Aggregate" function to it. As a result, a surface (grid) with a smaller cell size (15 by 15 meters) was created using the "Average" function for calculating the values of the generalized cell. In addition to the "Average" value, the tool allows you to calculate other functions for the output cell values: Total (Sum), Minimum (Min), Maximum (Max), and Median (Median). In the next stage, the "Aspect" tool for calculating directions of removal was used. Next - cell centers of the resulting surface are exported in point shapefile using the "Raster to point" tool.

The gradient (surface slope) was calculated using the "Slope" tool and the resulting values for each raster cell were added to the previously created point shape-file using the "Extract multi values to points" tool. Additionally, you allow specify a generalized grid with a surface of relief as the input surface and obtain the values of the removal direction at each point. As a result, the created point shapefile will contain three additional fields with the necessary values.

At the last stage of determining the direction of removal, the resulting point shapefile was formed. A classification with using the "graduated symbol" method was applied, and the "arrow symbol" as a symbol was used. The rotation using values from the field with the direction of removal was set. As a result, a map with vectors of the direction of removal was produced. Obtained map clearly demonstrates the direction of removal on the studied area.

Constructing of lines of positive forms of relief. To calculate lines on the surface of relief, the "Create Steepest Path" tool located on the toolbar of the ArcGIS 3D Analyst optional module was used. This tool calculates the direction in which a ball put in definitive point on the surface, would...
roll. Sampling points containing gold were taken as points on the surface. The construction of the maximum slope path is based on that the assumed ball will roll down to maximum slope path until it reaches the perimeter of the surface model, or until it falls into a deepening. At the end of this procedure, a 3D graphic line on the map was created [10, 11].

However, because, the assumed ball is rolling down, and to solve the problem of searching for sources, we need an upward direction, the processed surface was "turned out". For the procedure "turn out" of the surface of relief, the "Map Algebra" tool of the ArcGIS Spatial Analyst additional module was used, where the raster surface is multiplied by the value "-1". As a result of this procedure, for the raster surface, the reverse values were set, and the slopes were turned to the opposite direction (uplands turn into depressions and vice versa) [12].

4. Research results
As a result of the calculations, the lines that reflect positive forms of relief – ridges and steep slopes that could be a source for sediment removal were constructed. For the geological interpretation of these lines: a structural scheme with folds of area, and a map of gravitational anomalies that show the areas of syenites and crystalline schists were used (figure 1, figure 2). As a result of this combination, we can observe that the constructed lines reflect the strike of geological structures (figure 2).

For the area near the P. Pinyin deposit marked on the figures with letter A, the lines are sub-parallel to the synform axes located near them. These synforms most researchers associate with the presence of mafic crystalline schists [13]. The gravitational field due to the relatively high density of these crystalline schists is characterized by an increased value of intensity. For areas marked with letters B and C, the same regularities are noted (figure 2).

In the areas marked with letters D-G, several groups of lines are observed. One group of lines is stretched along the axis of the anticline fold (figure 2). The other group is directed across this axis (figure 2). Probably the first group reflects the folds and the second - faults.

Field works were carried out on the lines adjacent to the areas marked with letters A and B. The researches were aimed at identifying signs of gold content and point sampling of rock debris (boulders). Microprobe analysis was carried out in rock debris samples.

Two microinclusions of gold confined to the contacts of albite with pyrrhotite and clinopyroxene were found in the fragments of clinopyroxene-feldspar rocks with ± quartz, ± biotite on the line adjacent to the area marked with letter A.

On the lines adjacent to the area marked with the letter B, in the fragments of biotite-pyroxene and biotite-amphibole-dipyroxene crystalline schists: microinclusions of gold and microinclusions of argentite and pyrrhotite were found in the cracks in plagioclase and diopside; microinclusions of argentite and pyrite in scapolite were discovered. In a fragment of recrystallized pyroxene-amphibole crystalline schist, microinclusions of argentite and wolframite in cracks in potassium feldspar were discovered.

On some of the lines, microinclusions of gold and silver minerals in rock samples were not detected (figure 2). Lines near the areas marked with the letters C-G were not examined.
Figure 2. Location of calculated lines on the structural scheme. A map of the gravitational field is used as the background. The scheme is based on the materials of "Yakutskgeologia" JSC. Brown shows the distribution areas of Precambrian schists, green - the distribution areas of Mesozoic igneous rocks. 1 – calculated lines of positive forms of relief; 2 – the points where rare microinclusions of gold and/or silver were found; 3 – the point where gold wasn't found; 4 – anticline folds axes (Vs-Vasilievskaya, Ur-Uryungskaya, ML-Malolegierskaya, Kn-Kankunskaya); 5 – syncline folds axes (Lg-Legierskaya, Kr-Korotskaya); 6 – gold placer deposits; 7 – gold and lead flows; 8 – gold deposits and occurrences; 9 – points of gold mineralization in deluvium; 10 – studied areas (from A to G listed in figure 1).

5. Discussion
Modeling plays an important role in the study of the geological structure and processes of rock formation. Tectonic processes and the formation of clastic rocks are associated with the action of mechanical movements in the processes of orogeny and denudation [14]. The development of modeling methods using algorithms for mechanical movement on these objects seems logical. The method proposed in this paper was previously tested for gold prospecting in metamorphic complexes of the Prikolyma uplift and gave a positive result [12] (figure 3). It seems rational to use this technique to decipher tectonic structures and search for minerals associated with magmatic complexes.
6. Conclusions

Igneous rocks among metamorphic complexes, uplifted along the margins of the North-Asian craton are marked by positive landforms. Modeling of the ridges and steep slopes can be informative to understand the geological structure of the territories and to search for minerals associated with igneous complexes. In connection with the research of the landform processes the methods for modeling mechanical movements require development.

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