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Research Article

DETECTING ACTIVE FAULTS AND TRACING FRACTURED ZONES USING DEM PROCESSING

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Abstract:

This article describes the technique and results of digital DEM digital processing conducted for the territory of a small oilfield. The study aims to obtain information on rock mass natural fracturing and fluid dynamics. Although only one particular case is described here, the proposed technique is universal and can be applied to any flat area with developed erosional system (within the platforms). Results of DEM digital processing in conjunction with oil content data, geochemical sampling and high-precision gravimetry were used to discover zones of excessive fracturing and fluid dynamic activity in sedimentary cover. Also, block model of the oilfield was constructed, and reconstruction of geodynamic processes in the active microblocks junction zones was carried out.

Keywords: geodynamics, morphometric analysis, lineament analysis, DEM.

1. Introduction

Examples and methods of digital elevation models (DEM) transformation in order to obtain an information about the geodynamic state of the underground structure are well known and have been used by geologists before the advent of computers [1,2].

In Russian petroleum geology morphometric analysis was used for decades to search for oil-bearing structures and lineament analysis, as a universal method for studying fractured rock massifs. Currently, interest in the subject is increased due to the fact that new ways of DEM creating and processing (remote sensing data, high-precision geodesy, laser scanning, photogrammetry, GIS) provide not only detailed models for large areas, but also the opportunity to extract from DEM much more information than it was possible by manual processing of cartographic material [3].

Even outdated DEM can provide a lot of useful information about geodynamical conditions of subsoil, because in geological time scale topographic map created in the last century is as relevant as cur-rent maps. Data on the natural fracturing of rocks and fluid dynamic state are important at all stages of oil exploration as well as during field development, when EOR programs should be effectively performed, i.e. hydraulic fracturing etc. Planning for such programs requires reservoir model which is as precise as possible and which takes into account the natural fracturing of rocks. This article describes the technique and results of the digital processing of different scales DEMs conducted for the territory of a small oilfield and the zones of excessive fracturing and fluid dynamic activity in sedimentary cover were indicated in conjunction with oil content data, geochemical sampling and high-precision gravimetry.

2. Study Subject and Methodology

2.1. Study subject

The area of interest is Akanskoye oilfield (147 sq. km.) which is located in the South part of Tatarstan Republic. The faults inside the area of Akanskoye oilfield created a cross system, which is responsible for crystalline basement compartmentalization to the blocks. The tectonic movements of these blocks determine the structural separation of sedimentary cover's uplifted areas. The tectonic elements traced basing on the surface of crystalline basement, generally, can be traced in the overlying Paleozoic horizons also. The oilfield has very complex geological structure and reservoir properties distribution. Commercially oil-bearing horizons are carbonates of Early and Middle Carboniferous. A bitumen deposit is detected in upper horizons. In the nearest future hydraulic fracturing is planned in Akanskoe oilfield to increase oil rates. Therefore, the main goal of the study was to detect the intensively fractured zones with an active fluid-dynamical state, zones of tectonic faults and to estimate modern geodynamical activity in general.

2.2. General research technics

Main method of study was lineament and morphometric analysis of DEM. The realization of the methods is different from the traditional one due to use of specialized software of extraction and statistical processing of lineaments LESSA [4] and geoinformational system ArcGIS 10 (ESRI, USA). The initial data for the calculation of the maps of lineaments of different extent and the maps of the density of lineaments was DEM of the area of study with the scale of 1:50000. Morphometric analysis with an advanced technique of V.P. Filosov [3] was made for DEM of 1:50000 scale (detailed study) and 1:200000 (to take into account the regional background).

The relationship between the relief elevation, shapes and erosional networks was studied by many scientists [5,6,7,8,9,10]. The result of many years of research is a number of conclusions, which are currently accepted by geologists and geomorphologists as basic scientific principles. In this study these principles are the basis of all the techniques used:-erosion processes are usually developed along the weaken, erodible zones of rocks. Among them there are zones of tectonic crushing, extension fractures etc. River valleys of low order and different types of dry valleys, including gulleys, associate with the zones of the most intensive fracturing. In the same time in watershed areas belonged to the zones where rocks were less fractured;

-valleys are located along the fractures, however not all of the fractures, faults, cracks, and other types of linear tectonic dislocations give rise to the valleys. According to V.E. Khain & M.G. Lomidze [11], rivers belongs only to those faults which were active in the Neogene-Quaternary. The same circumstance is shown by and L.C. King [12].

-constant circulation of a groundwater is observed on the active tectonic fractures, that contributes to the valley appearance. Rivers take place only in the areas where a natural discharge of groundwater is located, and where linearly elongated decreases in the relief are presented. Often, the modern river network inherits the older. This obviously, it is associated with the establishment of the groundwater state in accordance with the tectonic structures. Un-der these conditions, rivers get a surface and a stable underground alimentation [1].

The information mentioned above suggests that the modern valley (river) network is an image of neotectonic dislocations network, which forms the modern relief. Consequently, the linear elements of the river network can be considered as linear elements of a network of faults. The fault network itself limits the more stable areas of the earth's crust – blocks and microblocks. Obviously, the high order valleys limit larger tectonic structures (blocks), the valleys of middle and lower orders – smaller structures (microblocks). According to this principle block structure of the crust was identified in the study area.

2.2.1. Lineaments analysis

The calculation of strokes and all the derived fields (lineaments, roses and density) was performed by the method of A.A. Zlatopolsky using LESSA program [4]. To define the strokes, rectified sections of ridges and valleys are identified in DEM. For each cell of DEM the direction of the strokes is defined with a precision of 22.5 degrees (one of the following 8 directions: 0, 22.5, 45, 67.5, 90, 112.5, 135, 157.5). The reliable identification is available only for the strokes smaller than 5-10 pixels. Next step of the strokes analysis is a creation the straight, prolonged lineament basing on strokes. At this step the filter selecting the lineaments according to their severity can be applied selecting lineaments according to their severity. The use of DEM of large scale allowed to conclude, that the crust consists of elementary blocks with one major direction of faults. An orientation of the elementary blocks was defined using the local rose diagrams. Local roses were calculated basing on the initial map of the strokes using the sliding window method with the size of 64x64. For each local rose the vector of maximal elongation was calculated showing the dominated direction of fractures inside the processing window. The same vector is a direction of maximal lineament density. The map of primary strokes was used to calculate the map of macrofissuring of sedimentary cover (the density of the stroke) in addition to calculating the lineaments and their directions. The value of each cell in a raster of strokes density shows the ratio of total length of all strokes over the area of a vicinity of a given cell (multiplied by 10000). The vicinity is a circle with a radius of 500 m, the cell size of the raster is 50x50 m. The density of strokes is an analogue of the traditional maps of horizontal relief dis-section.

The borders of microblocks (the smallest order blocks) were encountered using the center lines of erosion forms (line of valley bottom) taking into account the maximum elongation vectors of the local roses so that the orientation of the local fracturing within each microblock was mostly unidirectional. The vectors of prevailing directions of the fractures have the characteristic distribution: we see both, the field grouping unidirectional vectors, and the field of randomly distributed fractures. This fact indicates the existence of microblocks in crustal structure in different geodynamic conditions. During the tracing of the microblocks' borders the most severe lineaments line were also considered.

2.2.2. Morphometric analysis

To evaluate the intensity and the direction of movement for each block in the Neogene-Quaternary morphometric analysis of neotectonic structures developed by V.P. Filosofov for platform areas method was used. Technique was modified by the authors al-lowed to avoid the manual constructions and uses the tools of geoinformation system (GIS ArcGIS) [3,13,14,15]. For the field area the basis surface from 6 to 1 order were built, showing the stage of Akanskoe field area relief development. The difference between the basic surfaces that reflect the dynamics of the topography of the Quaternary period was built also.

Morphometric analysis allows dividing the DEM into several components (levels, or morphometric surfaces of different orders) corresponding to certain stages of neotectonic history. In this case, the difference between isobase surfaces of lower orders was the object of interest. Isobase surface is a surface integrating local base levels of erosion. Isobase surfaces are distinguished by their orders in accordance with the stream valley order. Valleys of the 1st order are those, which do not enter any other valley; valleys of the 2^{nd} order are formed by two merging valleys of the 1^{st} order; 3^{rd}order valleys are formed by two merging valleys of the 2^{nd} order, etc. [13]. Isobase surface of the 1st order integrates local bases of erosion of all orders; isobase surface of the 2nd order integrates local bases of erosion of the

2nd, the 3rd and all the other higher orders; isobase surface of the 3rd order integrates local bases of erosion of 3rd and all the other higher orders, etc. Isobase surfaces of lower orders just slightly differ from the surface relief. Without any tectonic movement, relief would be eroded to the 2nd order isobase surface at the beginning of the erosion cycle, and then it would degrade to the 3rd order surface, and so on. Valleys of the 1st order in lowlands are small channels cutting the slopes and hollows on watersheds. Hollows then turn into ravines or gullies, which subsequently become rivers. Under mild climate conditions, the river valleys with a constant water flow are usually of the 3rdor the 4th order. In the1st and the 2nd order valleys water streams are only temporary. It also has to be considered that some gullies are rather young (i.e. appeared in Holocene). Therefore, we can assume that the difference between isobase surfaces of the 1st and the 2nd order shows the direction and intensity of tectonic movements that occurred in the time period between modern and late stages of the relief evolution (until Pleistocene, ~1.6 million years) [14,15].

A complete analysis of the basis surfaces and their differences showed that at all stages of neotectonic history, excluding the last stage, the northern part of the Akanskoe field experienced mostly positive vertical movements, while the southern part was located in stable, non-active zone. In the late Holocene tectonic conditions were changed: now the southern part of the territory become active and the northern part is tectonically stable. Recent circumstances determine modern geodynamic conditions that are prevalent in the area of research.

Workflow for the DEM processing shown at Fig. 1

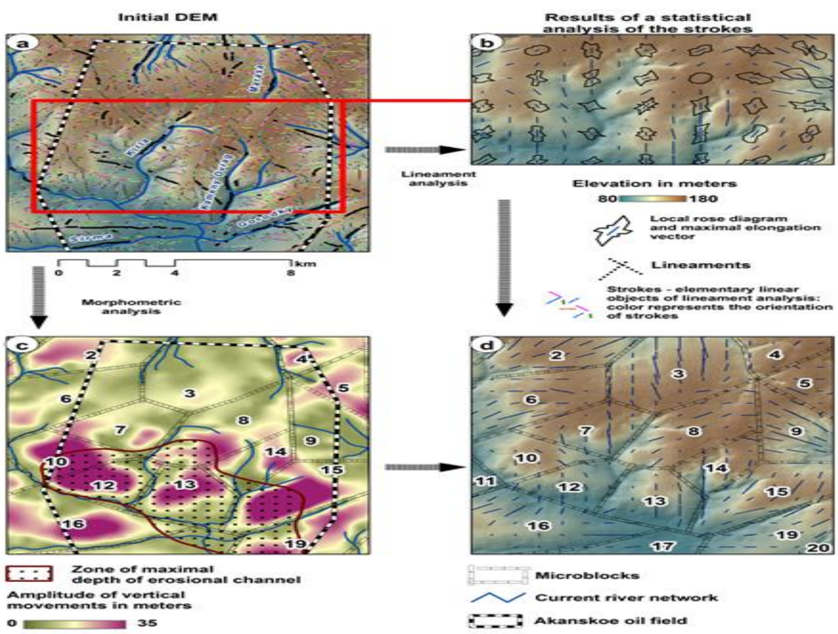

Fig.1. The results of a morphometric and lineament analysis: a) initial DEM of 1:50000 scale; b) fragment of local rose and maximal elongation vector map; c) difference of 1st and 2nd order basis surfaces; d) fragment of bock structure of the study area. Arrows show the data collection and processing algorithm.

3. Results and Discussion

The orientation of disjunctive dislocation lines identified basing on the crystalline basement rocks and the Devonian sediments (the results of previous seismic surveys conducted in the area), in plan view is close to the orientation of main lineaments identified basing on the results of lineament analysis of DEM.

The results of morphometric analysis show high intensity of erosion processes on the earth's surface in the area of interest, which is a common attribute of high geodynamic activity of the earth's crust.

The deposits, which are located in the zone of high geodynamic activity is currently subjected to intense process of destruction: their integrity can be ensured only through the "recharge" processes. Assuming that active faults are the main conductors of hydrocarbons and using the information on the dominant orientation of fractures within each block (ac-cording to lineament analysis), we can assume that the main direction of lateral migration of hydrocarbons within Akanskoe field is south-north.

From the position of geomechanics and geodynamics the common boundary zone of microblocks number 13, 14 and 15 is an object of interest (Fig. 2). Several signs indicate that this junction zone of 3 blocks is very active at the present stage: a) orientation of the disjunctive dislocation lines, traced by the crystalline basement rocks and Devonian deposits, in plan view is similar to the orientation of the main lineaments identified as the result of DEM lineament analysis (fault "a").

According to the lineament analysis high permeability zone is also detected in sedimentary cover; b) the morphometric analysis data showed a high intensity of erosion processes on the surface in the area of interest, which is a common feature of high geodynamic activity of this part of the earth's crust; c) an indication of the active mass transport in the nodal zone is the detection of soil sample with anomalously high propane content; d) according to the deep drilling data oil-bearing formations of the Lower Carboniferous are detected in Bobrikovian, Tula and Tournasian deposits. All the wells mentioned are located in the vicinity of fault «a». Other deep wells located in other parts of the licensed area show an absence of oil bearing formations in the Lower Carboniferous, while the oil deposits in the Middle Carboniferous are distributed almost throughout the field. This may mean that at this region the reservoirs of the Middle Carboniferous accumulate the new portions of hydrocarbons not only due to the flow of fluids from the Lower Carboniferous deposits, but also from other sources.

Obviously, the areas of high probability of cracks or fractures are unfavorable for work, associated with hydraulic fracturing.

4. Conclusion

The results of lineament analysis provide maps of generalized macroscopic permeability of the sedimentary cover, rose of global and local fracturing within the study area. Lineament analysis can be performed using both DEM of daylight surface and DEM of structural surface of sedimentary cover, which can provide additional information about the macrofissuring of sedimentary cover.

The combination of morphometric and lineament analysis allows to trace the block boundaries more precisely, and as the morphometric analysis provides a direction and evaluation of the amplitude of the earth's surface vertical displacement – it's possible to trace the dynamics of each selected block's movements in Neogene-Quaternary. Finally, possessing an information about the microcracks' direction, the sign and the intensity of the vertical displacements of the blocks, potential directions of fluid migration and possible hydrocarbons localization can be identified.

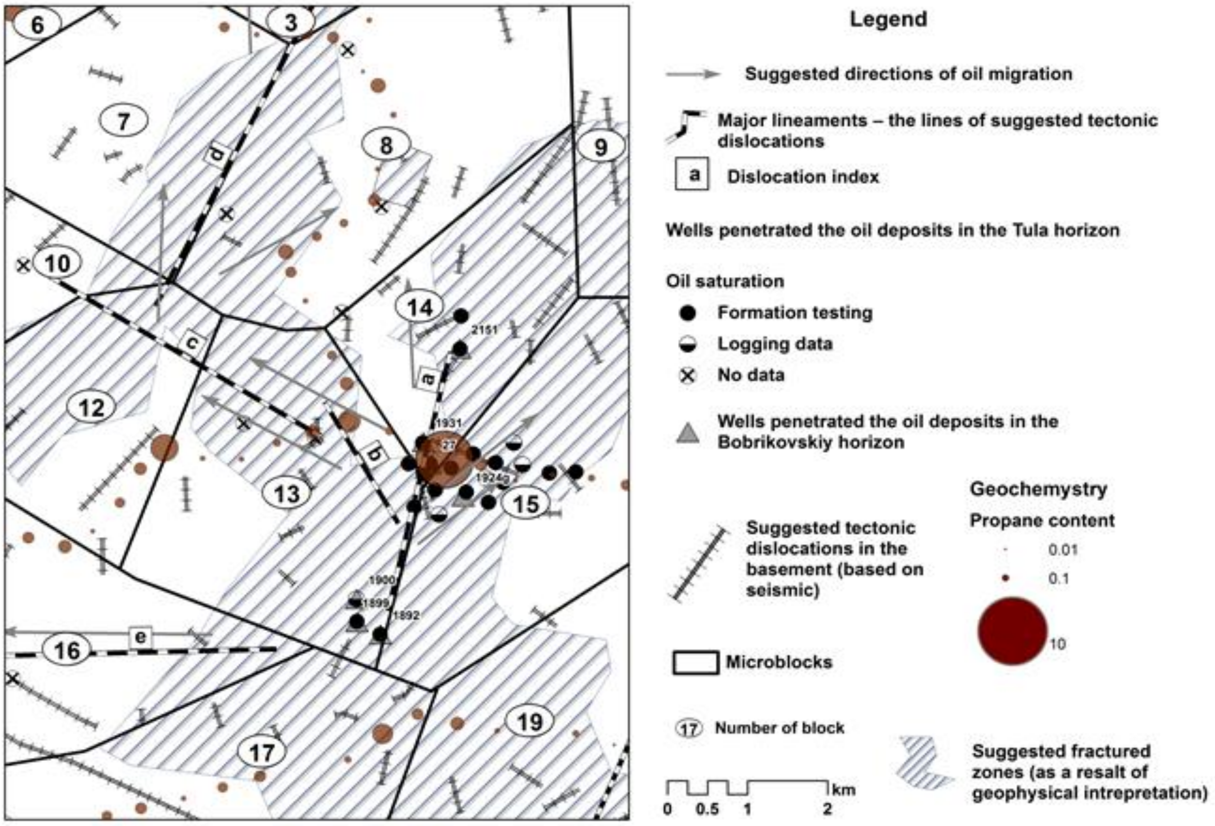

Fig 2. Reconstruction of geodynamical processes in the zone of microblocks junction and the map of fractured zones.

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