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# APPLYING THE COMBINATION OF GIS TOOLS WITH UPGRADED STRUCTURAL AND MORPHOLOGICAL METHODS FOR STUDYING NEOTECTONICS

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*Abstract*

Structural and geomorphological methods are often applied to the search for small oil-producing structures. Morphometric analysis of digital elevation models has proved to be the most informative one. Morphometric surfaces can be used to evaluate the direction and amplitude of vertical movements, to outline local and regional neotectonic structures and assess their petroleum saturation. This paper shows how to enhance the traditional morphometric analysis with GIS (geographic information systems) tools. A manifold increase in the efficiency of morphometric analysis takes it to a qualitatively new level. Setting specific parameters for some geoprocessing tools (for example, stream network tools) can be very important when studying local structures in small areas. In case of large territories, the output result is almost independent of the calculation errors. The improved technique proposed in this paper was tested on a large territory located in the Volga region. As a result, high-order morphometric surfaces were obtained, which was not possible before. In addition, a statistically significant relationship was discovered between morphometric surfaces and distribution of oil deposits, which can be considered a reliable prospecting indicator in the Volga-Ural petroleum province.

***Keywords:***
Neotectonics;
Structural and morphological methods;
Geoinformation systems;
Hydrocarbon potential assessment.

## 1. Introduction

Today, geographic information systems (GIS) are widely used in most petroleum companies and have become the standard tool for managing spatial data. GIS are recognized for their impressive degree of capability for organizing and visualizing geological and geophysical data. Another advantage of GIS is their ability to provide either ready-made solutions or crucial clues for decision-making.

In addition, GIS have other important features, which were not initially introduced in them, but developed over the years along with the basic tools and functions. These are unique capabilities of modern GIS, which can be considered a set of data processing methods that can be used for developing other scientific techniques. This feature of GIS has not yet been talked about enough. Meanwhile, features like this are in demand in the earth sciences and can provide researchers with non-trivial tools that are able to produce new information about the objects under study.

As will be demonstrated, ArcGIS (professional desktop GIS application) can be used to improve and transform the morphometric analysis for the purposes of searching for petroleum bearing neotectonic structures.

Morphometric analysis was invented in the late 60s – early 70s. It was one of the most popular and informative methods of petroleum prospecting within the platforms. At the time, a purely cartographic approach was followed, and ordinary topographic maps were used as input data. The most committed developers of the method were V.P. Filosofov and A.N. Lastochkin [1-4], who, together with other researchers [1-7], proved the high informative value of the method. However, from a technical point of view, this method had quickly become exhausted, since all calculations and plotting of morphometric surfaces were carried out manually. This method has been almost forgotten by now. However, right now the morphometric methods can be utilized to their full potential: modern GIS (ArcGIS in particular) greatly reduce technical difficulties and take morphometric analysis to a whole new level.

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The interesting thing about morphometric analysis is that it allows the reconstruction of neotectonic events over the entire study area. This is very rare for geomorphological and instrumental methods of studying neotectonics. Moreover, its application is not limited to local structures: this method can be successfully applied to petroleum prospecting on large territories.

Reliability of the result obtained is of utmost importance as well. Therefore, when developing a new methodology implementing GIS along with morphometric analysis, studies were carried out in three directions: 1) redevelopment of morphometric analysis techniques based on spatial data management methods; assessment of their effectiveness; 2) assessment of the reliability of morphometric maps obtained using the new techniques; 3) evaluation of the morphometric surfaces suitability for petroleum prospecting.

## 2. Methodology

Before turning to the new methodology and the results of its application, let us discuss the key provisions of morphometric analysis and traditional map making, which were comprehensively described by V.P. Filosofov [4].

### *2.1. Traditional (non-computer) morphometric analysis*

Morphometric analysis is based on the fact that the vast majority of modern tectonic movements are inherited. This means that uplifted structures have a tendency to ascend, while depressions tend to further descend. Every movement of the earth's crust that powers through exogenous processes is reflected in the modern landscape and river networks. Morphometric analysis decomposes the landforms into components (levels) attributed to different stages of the neotectonic history. The components represent tectonic structures of different scales. These structures can be ranked by the time of formation and assessed in terms of intensity of vertical movements and erosion.

The essence of morphometric analysis is construction and interpretation of a series of morphometric maps: maps of stream orders and watersheds; maps of base and top surfaces; difference surfaces; maps of erosional downcut depth, etc. Analysis of these maps makes it possible to discover and outline neotectonic structures of different orders.

The analysis starts with maps of stream orders. The stream order is determined using the Horton law [8]. A stream, into which not a single other stream flows, is considered a first-order stream. When two first-order streams meet, a stream of the second order is formed, into which streams of the first order can flow. The confluence of two second-order streams produces a stream of the third order, into which streams of the first and second orders flow. A firth-order stream is formed at the confluence of two third-order streams, and so on.

First-order streams in the lowlands are usually runoff gullies appearing on watersheds. They further evolve into ravines and then into rivers. In the mild climate zones, river valleys with a constant water flow are usually of the third or fourth order. In the valleys of the 1st, 2nd, and sometimes even the 3rd orders, only temporary streams flow. Upward tectonic movements stretch the upper parts of the earth's crust and, as a consequence, crack the rocks. New stream paths occur along the newly formed cracks increasing the order of the old ones. Downward tectonic movements contract the earth's crust, and some of the cracks close. The valleys of the lower orders are then covered with sediments decreasing the order of valleys and watersheds within a large area.

First-order streams usually have similar lengths, basin areas and flow rates provided that they are under the same physical, geographical and geological conditions. Therefore they affect the landscape with approximately the same erosive force and react in the same way to tectonic events of the corresponding order. Streams of different orders show different sensitivity to structures of the same size and tectonic activity. Low-order streams are usually of Holocene and Late Quaternary age. High-order streams are much older. However, they can be made of fragments of different ages – put together by tectonic movements.

The order of watersheds is calculated in a similar way. A variety of morphometric surfaces can be constructed based on maps of stream/watershed order. The most popular ones are base and top surfaces and the difference surface.

Base surface is a surface that unites local bases of erosion. Base surfaces can be of different orders as well. Base surfaces are built as follows: 1) on the topographic map, streams of a given order are selected (if needed drawn manually); 2) the largest possible number of water edge marks are specified (including all intersections of streams and contour lines); 3) equal water edge marks for each of the streams are connected by isolines – isobases, cutting through watersheds (fig.1a).

First-order base surfaces unite local bases of erosion of all orders. Second-order base surfaces unite local bases of erosion of the 2nd, 3rd and higher orders; third-order base surfaces unite local bases of erosion of 3rd and higher orders, etc.

Low-order base surfaces differ insignificantly from the surface topography. If there were no tectonic movements, then at the beginning of the erosion cycle the terrain would be washed out to the base surface of the 2nd order, then to the base surface of the 3rd order, etc., gradually leveling the terrain to the base surface of the highest order. The base surface of the highest order is practically the denudation surface to which the terrain gravitates toward.

Top surface is an enveloping surface that passes through watersheds. Top surfaces are located above the modern terrain. Top surfaces can be of different orders as well. Top surfaces are built as follows:

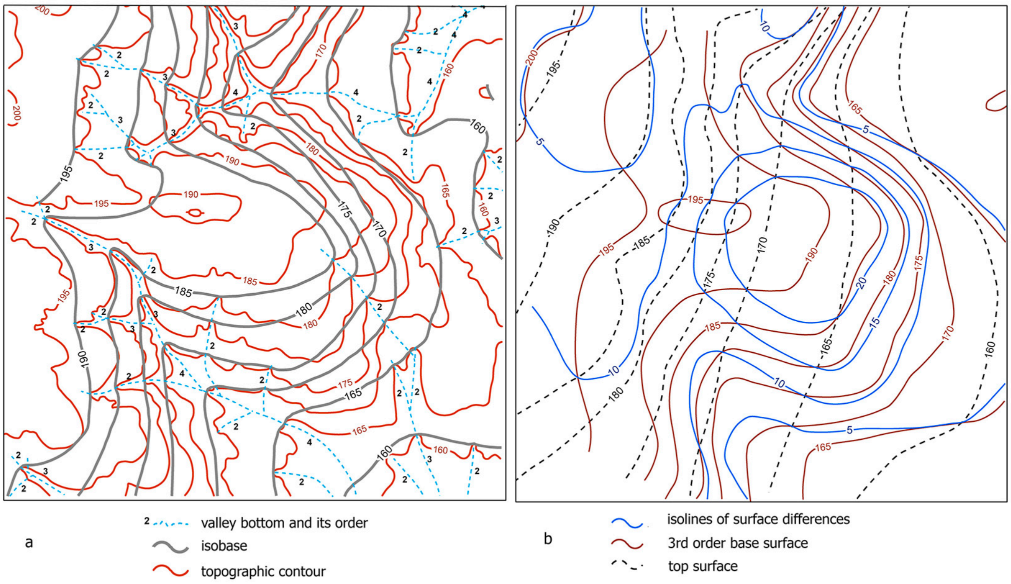

**Fig. 1. Traditional method of creating morphometric maps: a) base surface of the 2nd order based on the valley bottoms of 2nd and higher order, b) difference between top and base surfaces of the 3rd order (the Filosofov method [4])**

1) watershed lines of equal order are transferred to a topographic map, and their heights are specified at the intersections with the contours; 2) the points with the same height are connected by smooth lines – isohypsobases.

Before, difference surfaces were constructed by graphical subtraction [4]. A sample of the difference between top and base surfaces of the 3rd order is shown in figure 1b. Manual labor like this was painstaking and often ineffective. Sometimes contour lines of different types were almost parallel, and graphical subtraction was impossible. In these cases, the subtraction was performed along profiles. Large number of profiles ensured the required accuracy. In the case of lowlands, the distance between the profiles on the map should not have exceeded 2 centimeters.

A simple listing of actions needed for construction of just one morphometric surface speaks of the enormous amount of work that geologists had to overcome manually. High labor intensity did not allow the use of morphometric analysis for large territories or the construction of high-order base and top surfaces. Geologists were forced to keep their studies within small areas.

Today, every ArcGIS user knows how simple surface subtraction is with the Spatial Analyst Raster Calculator. Creation and analysis of morphometric surfaces in ArcGIS can be automated as well. Chapters 2.2 and 2.3 describe the technology behind morphometric analysis in ArcGIS Desktop ver.10.x.

### *2.2. Computer-aided method for building and analyzing morphometric maps*

Computer-aided method for building and analyzing morphometric maps allows breaking away from presenting surfaces as a set of isolines. They can be smooth continuous surfaces or 3D images instead. ArcGIS has more than 20 tools [9] designed specifically for hydrogeological modeling and construction of topographic surfaces, which can take into account all morphometric features of the study area. Because these tools work with raster data, the way maps are generated and interpreted differs significantly from what can be done with traditional approach.

New methodology for building and analyzing morphometric maps was tested on a large area in attempt to interpret the maps at a regional scale. Digital topographic sheets (scale 1:200000, 105 sheets in total, covering 9 large regions in the basins of the Volga and Kama rivers) were used as input (fig.2).

The following preparations were made: 1) adjustment and alignment of the sheets; 2) generalization of polygonal water bodies (large rivers) into linear objects; 3) elimination of topological and attribute errors; 4) creation of a river network; 5) creation of a digital elevation model (DEM).

**Fig.2. Overview map**

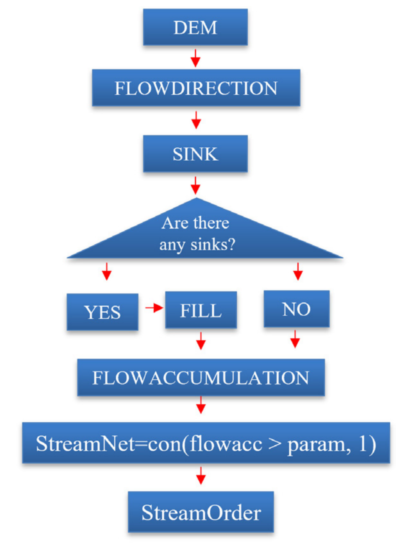

**Fig.3. Construction of a stream order map**

The DEM was created with the TOPOGRID tool from the ArcGIS Spatial Analyst toolset. The TOPOGRID [10-12] produces a model, the quality of which exceeds the quality of those obtained with conventional interpolation methods, such as, spline or kriging. This tool takes account not only of isolines and elevation marks, but also of river networks, lakes and local depressions. There are also a number of additional TOPOGRID options that allow construction of hypsometric surfaces suitable for hydrogeological modeling. The grid cell size was 200x200 m, which provides sufficient accuracy for regional studies and does not complicate the calculations.

The map of stream orders was constructed from the terrain grid using ArcGIS special hydrogeological tools (FLOWDIRECTION, FLOWACCUMULATION, STREAMORDER) (fig.3). The result was a raster model of the stream network. The last step of hydrological modeling implied conversion of the raster model into vector model, where the order of each stream in the network was calculated (fig.4).

ArcGIS uses well-known algorithms [13, 14] for drainage networks, which, however, have their weaknesses. Sometimes they produce artifacts (false first-order streams) in smooth or plain areas of the DEM. These shortcomings have been repeatedly discussed in the literature. J. Fairfield and P. Leymarie [15] sum it up and give recommendations on how to prevent the artifacts or at least reduce them. Fortunately, this kind of artifacts does not affect the results of morphometric analysis.

As a result, 10 orders of river valleys were obtained. The rivers Kama and Volga turned to be the highest-order (9th) streams in the study area. Once the Kama flows into the Volga, the latter becomes the highest-order (10th) stream (fig.4).

Manual construction of base surfaces involved the intersections of streams and contour lines. Computer-aided method utilizes a different technique. To obtain a set of XYZ points, two ArcGIS tools were used: 1) «Feature Vertices To Points» transforms a linear pattern of streams into a point pattern. The output is a set of points (vertices) preserving the stream’s shape and information about its order; 2) «Extract Values to Points» extracts Z-coordinates from the DEM into the points obtained in the previous step.

The TOPOGRID tool (with a grid size of 200x200 m) was also used for the construction of base surfaces. All difference surfaces were calculated using the Raster Calculator from the Spatial Analyst toolset.

### *2.3. Optimization of the algorithm*

The most controversial step of calculating the stream order is the numerical parameter «param» of the Con function (fig.3). For each raster cell, the Con function determines how many other cells will drain water into that cell (based on the slope). Low values of the «param» may produce a model with a large number of small tributaries, many of which usually turn out to be artifacts. High values of this parameter, on the other hand, can totally erase all small streams for the model. Therefore, it is necessary to tailor this value to the reality.

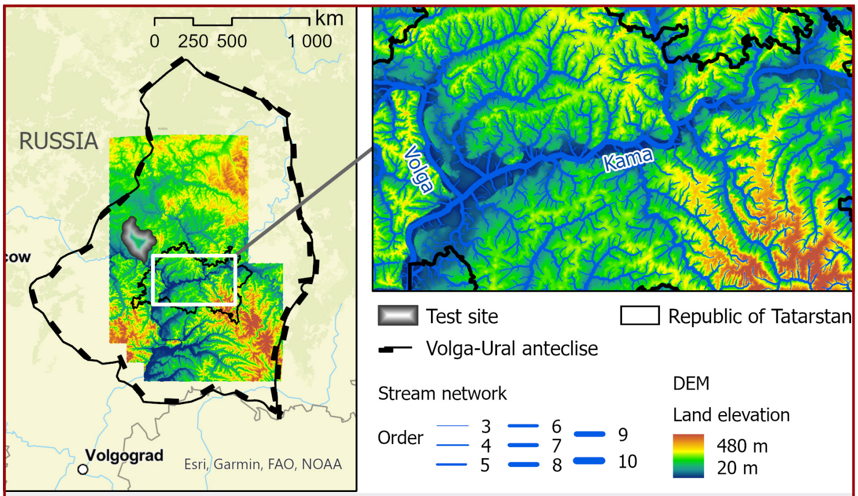

**Fig.4. Digital elevation model. The inset map on the right shows a fragment of the DEM overlaid by the stream network. The figure also shows the test site**

It was determined empirically. Several stream models were built with different values (from 30 to 150 with a step of 20). For the optimal value, the models were compared with the reference model created for the test site.

An area covering the basins of two large rivers was chosen as a test site. For this area, the model was constructed manually, in accordance with the recommendations of Horton and Filosofov. Based on the topographic contours, the valley bottoms were manually digitized, and their orders were calculated. Comparison of the «manual» and «computed» stream models showed that the best match was achieved with the «param» value set at 75. Next, the morphometric surfaces were constructed on the basis of «manual» and «computed» stream models, and then compared.

Morphometric analysis focuses on behavior (or shape) of the base surfaces rather than the absolute elevations. Therefore, correlation ratios between morphometric surfaces constructed using different methods were calculated. Such a comparison shows whether the algorithm is stable and produces correct results.

The correlation ratios are presented in Table 1. They are high enough, which proves that automatic construction of base surfaces produces a very good result. The shape of surfaces constructed by different methods is practically the same.

However, difference surfaces diverge a little. The reasons for this may be:

1. Interpolation errors that occur when constructing base surfaces.

2. Incorrect stream orders. There are at least two sources of errors: a) deficiencies in geoprocessing tools used for modeling and calculating stream orders; b) and subjective approach to identifying individual streams and determining their orders in a manual method. As a result, the maximum and minimum elevations of two morphometric surfaces may shift in space relative to each other, and the correlation between the surfaces will decrease.

**Table 1**

**Correlation ratios between morphometric surfaces constructed using two methods: in automatic mode and manually (according to the traditional method)**

| Morphometric surface | Correlation ratio |
|---|---|
| 1st order base surface | 0.98 |
| 2nd order base surface | 0.97 |
| 3rd order base surface | 0.97 |
| 4th order base surface | 0.96 |
| 5th order base surface | 0.96 |
| Difference between 1st and 2nd order base surfaces | 0.61 |
| Difference between 2nd and 3rd order base surfaces | 0.64 |
| Difference between 3rd and 4th order base surfaces | 0.69 |
| Difference between 4th and 5th order base surfaces | 0.68 |

An interesting fact is that increase in the steam order increases the correlation (Table 1). This is important, because the most interesting are the difference surfaces of higher orders, which provide information on large structures and their evolution at different stages of the neotectonic history. Therefore, at a regional scale, the errors of the automated approach can be ignored. However, in case of small active structures, the results of GIS-aided morphometric analysis should be cross-checked.

## 3. Results

### *3.1. Assessment of credibility and effectiveness of the new method*

The advanced methodology described in Chapter 2.2 was applied to a construction of a map of stream orders, base surfaces and difference surfaces.

Base surfaces are static maps. They reveal static links existing between morphometric surfaces and tectonic structures without taking into account their evolution [4]. Base surfaces of the lowest orders (1st and 2nd) resemble the surface terrain. Surfaces of higher orders are noticeably different. They reveal the largest neotectonic structures.

The initial data allowed constructing of base surfaces up to the 8th order. Eight orders of surfaces allow calculation of seven difference surfaces (if only the surfaces of adjacent orders are selected for this). Therefore, seven stages of neotectonic evolution of the study area were identified. For each of them, the difference surfaces show the algebraic sum of vertical movements in the area: differences between 1st and 2nd order surfaces and 2nd and 3rd order surfaces cover the latest stages of neotectonic activity; differences between 3rd and 4th order surfaces (and higher order surfaces) cover the early stages of neotectonic activity. In other words, the difference surfaces give estimates of the amplitudes of vertical movements for a certain stage in neotectonic history.

To ascertain the validity of the aforesaid results, the structures identified on the morphometric surfaces were compared with: 1) the generally accepted tectonic maps of the region [16]; 2) the results of remote sensing data interpretation; 3) the results of field geomorphological studies.

The simple overlapping shows that the largest morphostructures coincide with the largest blocks of the earth's crust (fig.5): large positive morphostructures coincide with 1st order positive tectonic elements of the first order, while large negative morphostructures coincide with 1st order negative tectonic elements.

V.I. Burba and N.N. Nelidov have already applied geomorphological methods to the study of neotectonic movements within the Melekesskaya depression and the South Tatar Arch. They studied the formation of Pliocene folds based on pre-Pliocene terrain data, thickness of the Neogene section,

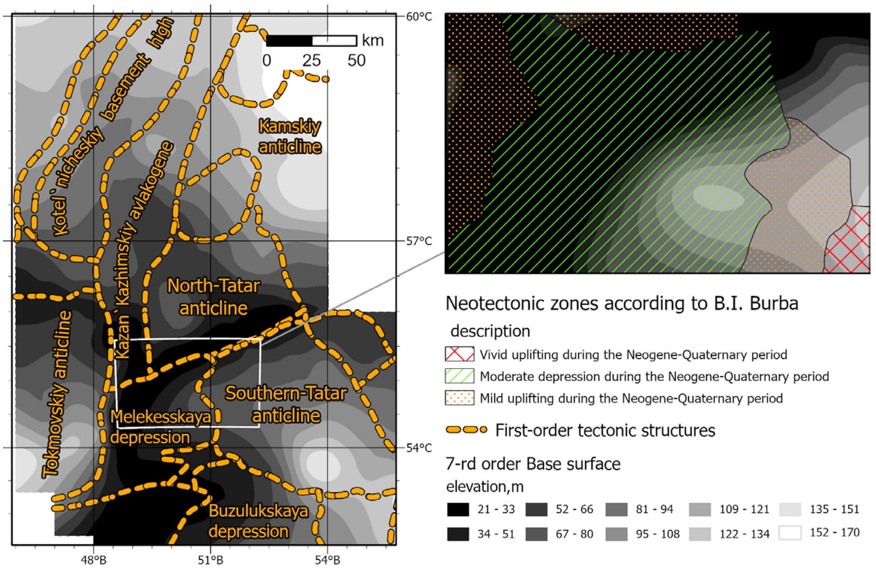

**Fig.5. Boundaries of 1st order tectonic structures overlapping the 7th order base surface. The inset map on the right is the map of neotectonic zones constructed for the Western Trans-Kama region by V. I. Burba overlapping the base surface of the 7th order**

and lithological and facies composition of Pliocene sediments [17, 18].

Comparison of the results obtained by different methods showed that the map of neotectonic zones constructed by V.I. Burba for the Western Trans-Kama region (Melekesskaya depression, western slope of the South Tatar Arch) almost duplicates the 7th order base surface. The base surface elevation reaches its maximum in the part that V.I. Burba has identified as an area of significant uplifting in the Neogene-Quaternary. The base surface elevation reaches its minimum in the part that V.I. Burba has identified as an area of subsidence in the Neogene-Quaternary. The transitional values correspond to the areas of mild uplift in the Neogene-Quaternary (fig.5).

V.I. Burba, N.N. Nelidov, A.A. Zharikov and V.K. Dyatlova [17-19] have discovered 48 local neotectonic structures on the territory of oil and bitumen fields of the Republic of Tatarstan during field studies. Figure 6 shows the contours of uplifted structures discovered by A.A. Zharikov overlapping the difference between the 4th and 5th order base surfaces.

Table 2 summarizes the results of comparing active structures identified on difference surfaces with structures identified during field geomorphological studies. It shows that almost all structures that were previously discovered by geomorphologists can be seen on morphometric surfaces as well.

The difference between the 1st and 2nd order base surfaces shows the direction and intensity of tectonic movements that occurred between the modern and the latest stages of the terrain history. Therefore, this difference surface reflects the current tectonic state of the study area. Overlaying a tectonic map based on Landsat imagery to the difference surface mentioned above confirms this assumption: the areas of the earth's crust that are active at present (with both positive and negative dynamics) coincide with the corresponding areas of

**Table 2**

**The number of neotectonic structures visible on morphometric surfaces**

| Difference surface | The number of structures visible on morphometric surfaces | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | V.I. Burba (28 structures) | | A.A. Zharikov (14 structures) | | V.K. Dyatlova (4 structures) | | N.N. Nelidov (2 structures) | |
| | Newly formed | Inherited | Newly formed | Inherited | Newly formed | Inherited | Newly formed | Inherited |
| 1st and 2nd order | 3 | 2 | no | 13 | no | 2 | no | no |
| 2nd and 3rd order | 6 | 4 | no | 16 | no | 4 | no | no |
| 3rd and 4th order | 4 | 7 | 4 | 18 | no | 3 | no | 1 |
| 4th and 5th order | 5 | 4 | 9 | 9 | 3 | 1 | no | 2 |
| 5th and 6th order | 2 | 1 | 6 | 4 | 1 | no | 2 | no |
| 6th and 7th order | 5 | no | 6 | | no | no | no | no |
| Total match | 25 out of 28 structures (89%) are a match | | 13 out of 14 structures (93%) are a match | | All 4 structures (100%) are a match | | All 2 structures (100%) are a match | |

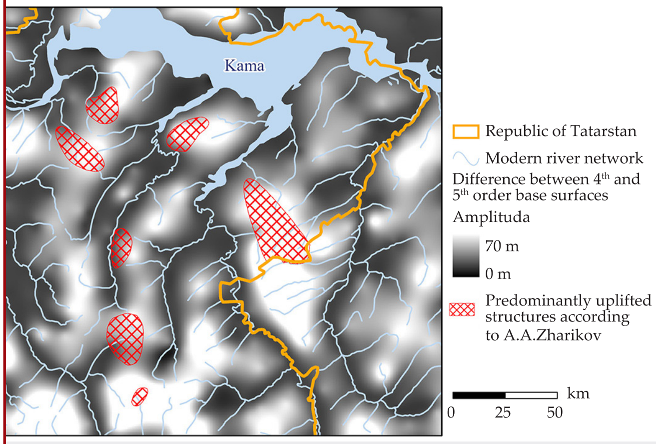

**Fig.6. Uplifted neotectonic structures clearly visible on the difference surface**

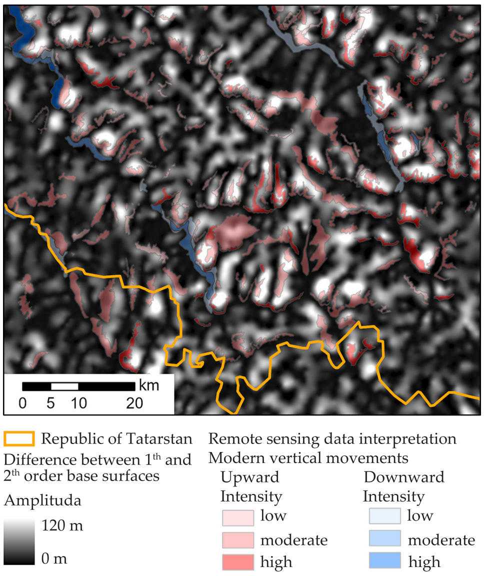

**Fig.7. Results of morphometric analysis (the difference between the 1st and 2nd order base surfaces) compared with the KA Landsat data**

the morphometric surface (fig.7).

The examples given above confirm the effectiveness of the morphometric method. GIS-aided morphometric analysis gives an adequate representation of neotectonic structures regardless of their order. And there is no ground to doubt the credibility of these results. With this technique, morphometric surfaces can be constructed hundreds of times faster, and the amount of work performed in one step exceeded all that was done manually over several years.

### *3.2. Evaluation of the effectiveness and efficiency of morphometric analysis as applied to petroleum prospecting.*

The creators of the morphometric method believed that 2nd and 3rd order morphostructures correspond to arches, dome-shaped structures and other positive structures of 2nd and 3rd order [4]. The morphometric method was used by them in search for oil-bearing local structures. In this regard, another basic provision, which was promoted at that time, was that only those structures that were active during the neotectonic period [5] can be considered promising. There were also different ideas [20, 1]. Anyway, there were few case studies, and no one could produce a statistically significant result for purely technical reasons. Today, this is possible. GIS can be used to conduct a comparative analysis of hundreds of structures and petroleum deposits. Therefore, one of the objectives of this study was to evaluate the effectiveness and efficiency of morphometric analysis as applied to petroleum prospecting.

In order to evaluate the effectiveness of morphometric analysis, the neotectonic histories of 4331 oil deposits located within the Republic of Tatarstan were studied. The deposits belong to different horizons of the Carboniferous and the Devonian. For each of the deposits, the geodynamic regime at different periods of its neotectonic history was determined. It is actually more accurate to talk about the part of the earth's crust where the deposit is now located, since the deposit could have formed after certain geodynamic regime (i.e., it can be younger). As mentioned above, the geodynamic regime (uplifting/subsidence/stable state) can be determined based on difference surfaces. To do this, on the difference surface, areas of relative (against the surrounding areas) uplift have to be outlined. In other words, the differences in base surfaces need to be classified by the direction and the amplitude of vertical movements. For the classification, the method for isolating the local component was used, which is suitable for any surface. The essence of this method consists in decomposing a difference surface into 2 components: global (background) and local (details). First, the global (background) component is calculated by averaging, and then the difference between the original surface and its background component is calculated. Circular and square filters were used for averaging. The shape and size of the filter were selected in such a way that the values of the local component had a normal distribution and the mean of 0. Next, the local component was divided into 3 classes by the standard deviation method: the first class included negative values, the second class included values close to the average (i.e. zero), and the third class included positive values. Thus, the first class reflects the subsidence, the second class corresponds to the transition zones (from subsidence to uplift), and the third class reflects active uplifting. This classification and identification of the geodynamic regimes was carried out for all seven difference surfaces.

Next step was to determine the state in which each deposit was at a certain stage of the neotectonic history. Neotectonic evolution of the region is reflected in the orders of the base surfaces. The changes that have occurred at each stage are recorded in the amplitudes of vertical movements. For each deposit, the geodynamic regime (uplifting/subsidence/stable state) at each of the seven stages of the Neogene-Quaternary was determined (based on 7 difference surfaces).

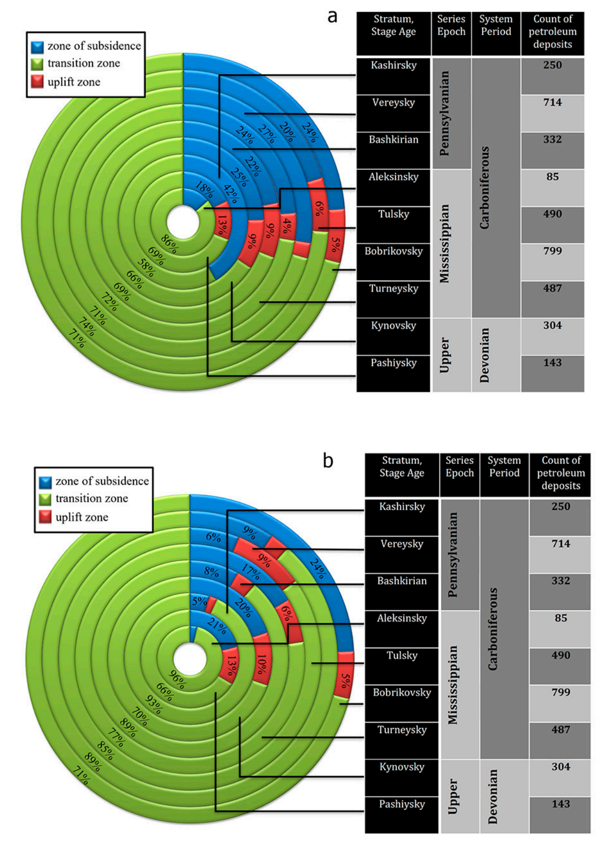

**Fig.8. The number of oil deposits (percentage of total) that existed under various geodynamic conditions reflected in the difference surfaces: a) 6th and 7th orders; b) 5th and 6th orders**

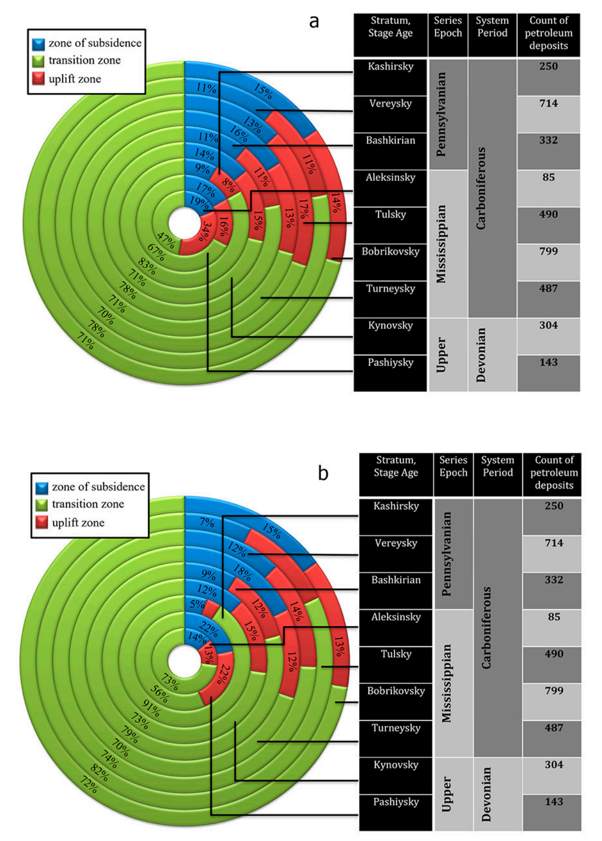

**Fig.9. The number of oil deposits (percentage of total) that existed under various geodynamic conditions reflected in the difference surfaces: a) 3rd and 4th orders; b) 2nd and 3rd orders**

The statistics presented in figures 8 and 9 show the summarized data on the geodynamic regime of deposits located in different productive horizons. The diagrams show that the vast majority of deposits, regardless of the depth, are located in transition zones. Figures 8 and 9 show statistical diagrams obtained for several difference surfaces (the rest of them look alike).

Transition zones are areas with a moderate neotectonic activity. Within these areas the deposits are located on the slopes of neotectonic uplifts. They experience ascending movements, but the amplitudes of these movements are 2-3 times less than those in the zones of intense uplifting (class 3 zones). Apparently, such a distribution of deposits is not random: areas with moderate upward tectonic movements create favorable conditions for the formation of petroleum deposits. The intensity of

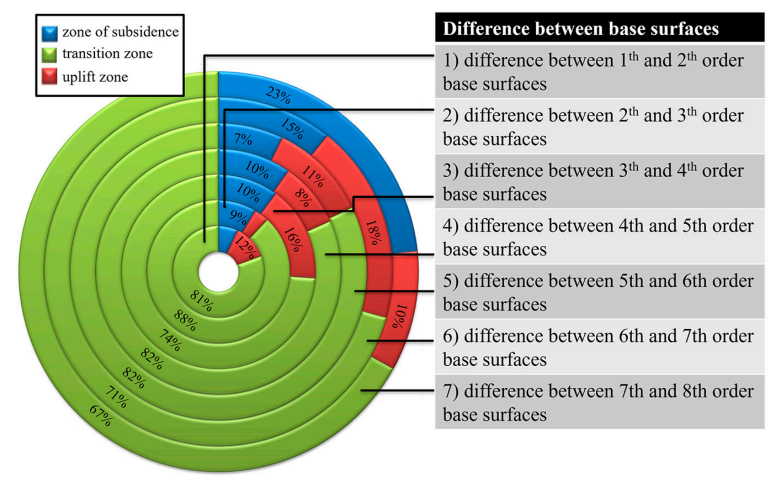

**Fig.10. The number of deposits (percentage of total) that existed under various geodynamic conditions during the neotectonic stage of geological history. These are all of the oilfields located within the Volga-Ural anteclise**

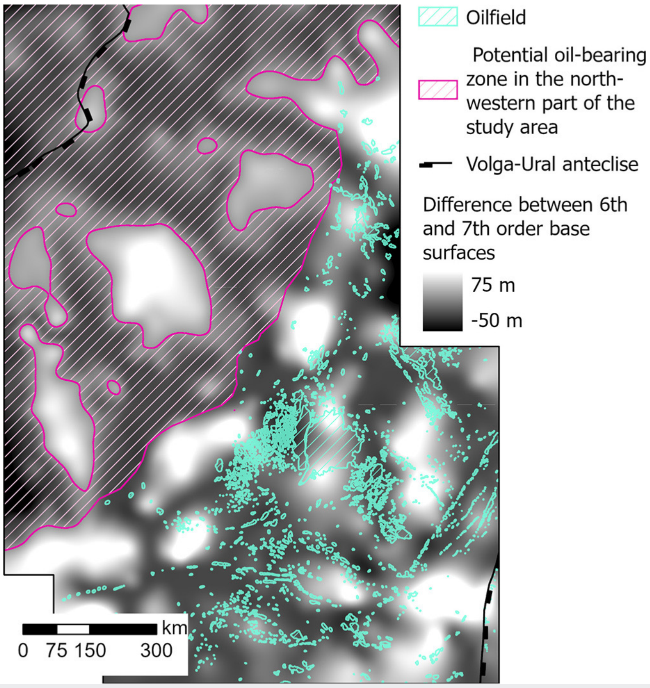

**Fig.11. Hydrocarbon prediction in the study area**

movements is sufficient to ensure the constant migration of hydrocarbons, but not excessive to the point of causing the cap rocks to break. In areas with high level of tectonic activity, the entire sedimentary cover cracks open, and hydrocarbons escape into the atmosphere. Thus, the results obtained during this study can be interpreted as the cooperation of two processes: formation and destruction of deposits in different geodynamic conditions.

Analysis of the oilfields distribution (without classifying them by productive horizons) leads to the same conclusions. The diagram presented in figure 10 shows that 67–88% of oilfields in the Volga-Ural anteclise are located in the zones with moderate geodynamic activity.

When overlaying the morphometric surfaces with the outlines of oilfields, obvious relationship can be observed between the location of oilfields and the morphometric surfaces of high orders (the 6th order base surface and the difference between the base surfaces of 6th and 7th order). Figure 11 shows that the vast majority of known deposits are located in depressions or on the slopes of uplifted structures. Thus, it can be assumed that the major migration of hydrocarbons (which consequently led to the formation of deposits) took place between the 7th and 6th stages of the region's neotectonic history. Following this principle, it should be possible to outline the areas where it is most likely to find a petroleum deposit. These areas are characterized by low amplitudes of vertical movements. The domes of rapidly rising neotectonic structures should be classified as unpromising and unproductive.

## Conclusion

The study confirmed that modern GIS provide tools and methods that can be used to enhance the traditional geological methods. The advanced technique of morphometric analysis presented in this paper illustrates this fact. The computer-aided method for conducting morphometric analysis proved to be highly efficient. Computer processing of spatial data relieves the researchers from unproductive formulaic work and makes the whole process of map-making unambiguous, free from the subjective element. For the first time, 8th order base surfaces were constructed, which is an extraordinary achievement for morphometric analysis. GIS-aided morphometric analysis produced new information on the tectonic evolution of the study area in the Neogene-Quaternary. The relationship between neotectonic structures and petroleum deposits in the Volga-Ural region was confirmed. This is a statistically significant relationship that can be used as a reliable prospecting indicator within the Volga-Ural petroleum province.

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### *References*

1. Lastochkin, A. N. (1974). Neotektonicheskie dvizheniya i razmeshchenie zalezhej nefti i gaza. *Leningrad: Nedra*.

2. Lastochkin, A. N. (1971). O formah proyavleniya razryvnyh narushenij v rel'efe Zapadno-Sibirskoj ravniny i strukturno-geomorfologicheskom metode ih obnaruzheniya. *Izvestiya VGO*, 1, 48-56.

3. Filosofov, V. P., Denisov, S. V. (1963). O poryadke rechnyh dolin i ih svyazi s tektonikoj. Morfometricheskij metod pri geologicheskih issledovaniyah. *Saratov: Izdatelstvo Saratovskogo Universiteta*.

4. Filosofov, V. P. (1975). Osnovy morfometricheskogo metoda poiskov tektonicheskih struktur. *Saratov: Izdatelstvo Saratovskogo Universiteta*.

5. Golodovkin, V. D. (1964). Tektonicheskoe stroenie Stavropol'skoj depressii po dannym morfometricheskogo analiza. *Kujbyshev: Trudi Kujbyshevskogo NII Neftyanoj promyshlennosti, Geologiya, geohimiya, geofizika*, 27, 45-47.

6. Muzychenko, N. M. (1962). Sovremennaya tektonika kamennougol'nyh otlozhenij Volgogradsko-Saratovskogo Povolzh'ya v svyazi s ocenkoj perspektiv ih neftenosnosti. Materialy po tektonike Nizhnego Povolzh'ya. *Leningrad: Gostoptekhizdat*.

7. Nourgaliev, D. K., Chernova, I. Yu., Nurgalieva, N. G., et al. (2013). Spatial variability of oil properties within oil fields of the Republic of Tatarstan. *Oil Industry*, 6, 8-11.

8. Horton, R. E. (1945). Erosional development of streams and their drainage basins Hydrophysical approach to quantitative morphology. *Bulletin of the Geological society of America*, 56.

9. McCoy, J., Johnston, K. (2001). Using arcgis spatial analyst. *U.S.A.: Environmental Systems Research Institute Inc*.

10. Hutchinson, M. F., Dowling, T. I. (1991). A continental hydrological assessment of a new grid-based digital elevation model of Australia. *Hydrological Processes*, 5, 45-58

11. Hutchinson, M. F. (1988). Calculation of hydrologically sound digital elevation models. In: *Third International Symposium on Spatial Data Handling at Sydney, Australia*.

12. Hutchinson, M. F. (1989). A new procedure for gridding elevation and streamline data with automatic removal of spurious pits. *Journal of Hydrology*, 106, 211-232.

13. Strahler, A. N. (1957). Quantitative Analysis of Watershed Geomorphology. *Transactions of the American Geophysical Union*, 8(6), 913-920.

14. Tarboton, D. G., Bras, R. L., Rodriguez-Iturbe, I. (1991). On the extraction of channel networks from digital elevation data. *Hydrological Processes*, 5, 81-100.

15. Fairfield, J., Leymarie, P. (1991). Drainage networks from grid digital elevation models. *Water Resources Research*, 27(5), 709-717.

16. (2003). Geologiya Tatarstana: Stratigrafiya i Tektonika. *Moskva: GEOS*.

17. Burba, V. I. (1972). Neotektonika Kazanskogo Zakam'ya. *Kazan': Izdatelstvo Kazanskogo Universiteta*.

18. Nelidov, N. N. (1960). Neotektonika Kazanskogo Zakam'ya. Geomorfologiya i novejshaya tektonika Volgo-Ural'skoj oblasti i Yuzhnogo Urala. *Ufa*.

19. Nugmanov, I. I. (2013). Vliyanie neotektonicheskih dvizhenij na razmeshchenie i sohrannost' zalezhej nefti i gaza (na primere Tatarskogo svoda i sklonov prilegayushchih vpadin). Dissertasiya na soiskaniye uchenoy stepeni kandidata geologo-mineralogicheskix nauk. *Kazan': Kazanskij (Privolzhskij) Federal'nyj Universitet*.

20. Travina, L. M. (1963). Primenenie morfometricheskogo metoda k poiskam struktur v severo-zapadnoj chasti Orenburgskoj oblasti. *Voprosy Morfometrii*, 2, 201-207.

## Усовершенствование и развитие структурно-морфологических методов изучения неотектоники с помощью инструментов ГИС

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### Реферат

Структурно-геоморфологические методы традиционно используется в нефтяной геологии для поиска локальных структур, перспективных на нефть и газ. Наиболее информативным из них является морфометрический метод анализа цифровых моделей рельефа. По морфометрическим поверхностям оценивают знак и амплитуду вертикальных движений, оконтуривают локальные и региональные неотектонические структуры, оценивают их перспективность на нефть и газ. Показано, каким образом традиционная методика морфометрического анализа может быть усовершенствована засчет использования инструментов геоинформационных систем. Многократное увеличение эффективности и информативности метода переводит его на качественно новый уровень. Параметры некоторых инструментов геообработки (например, инструменты расчета сети водотоков) могут быть критичными для ожидаемых результатов, если исследуются локальные структуры на небольших территориях. Результаты исследований для больших территорий почти не зависят от погрешностей алгоритма. Усовершенствованная методика была опробована на большой территории Поволжья. В результате были получены морфометрические поверхности высоких порядков, что ранее было невозможно. Обнаружена статистически значимая связь между морфометрическими поверхностями и распределением залежей нефти, которую можно рассматривать в качестве надежного поискового признака в Волго-Уральской нефтяной провинции.

***Ключевые слова:*** неотектоника; структурно-геоморфологические методы; геоинформационные системы; прогнозирование нефтегазоносности территорий.

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## Neotektonikanın öyrənilməsinin struktur-morfoloji metodlarının geoinformasiya sistemləri alətlərinin köməyi ilə təkmilləşdirilməsi və inkişafı

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### Xülasə

Neft geologiyasında neft və qazın perspektivli lokal strukturlarının axtarışı üçün ənənəvi olaraq struktur-geomorfoloji metodlardan istifadə olunur. Onların içərisində ən informativi relyefin rəqəmsal modellərinin analizi üçün olan morfometrik üsuldur. Morfometrik səthlərə görə şaquli hərəkətlərin işarəsi və amplitudası qiymətləndirilir, lokal və regional neotektonik strukturlar konturlanır, onların neft və qaz perspektivləri qiymətləndirilir. Geoinformasiya sistemlərinin alətlərindən istifadə etməklə ənənəvi morfometrik analiz metodunun necə təkmilləşdirilə biləcəyi göstərilir. Metodun effektivliyinin və informativliyinin dəfələrlə artması onu keyfiyyətcə yeni səviyyəyə qaldıracaqdır. Bəzi geoemal alətlərinin parametrləri (məsələn, su axını şəbəkəsinin hesablanması alətləri), əgər kiçik ərazilərdə lokal strukturlar tədqiq edilirsə, gözlənilən nəticələr üçün kritik ola bilər. Böyük ərazilər üçün tədqiqat nəticələri demək olar ki, alqoritm xətalarından asılı olmur. Təkmilləşdirilmiş metodika Volqa bölgəsinin böyük ərazisində sınaqdan keçirilmişdir. Nəticədə əvvəllər qeyri-mümkün olan yüksək səviyyəli morfometrik səthlər əldə edilmişdir. Morfometrik səthlər və neft yataqlarının paylanması arasında statistik əhəmiyyətli əlaqə aşkar edilmişdir ki, bu da Volqa-Ural neft əyalətində etibarlı axtarış göstəricisi hesab edilə bilər.

***Açar sözlər:*** neotektonika; struktur-geomorfoloji metodlar; geoinformasiya sistemləri; ərazilərin neft-qazlılığının proqnozlaşdırılması.