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# Investigation of Modern Movements in Geosites of "Kaniv Dislocations" by utilizing GIS

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**Investigation of Modern Movements in Geosites of "Kaniv Dislocations" by utilizing GIS. — Tustanovskaya, L., Grytsenko, V. —** Studies of the Kaniv dislocations started by Dubois de Montpereux (1832) and advanced significantly so that they have reached some hundreds publications. There are important sites that show significant have reached some hundreds publications. There are important sites that show significant all of those features are protected by Kaniv National Reserve authority. This unique area has outcrops of Mesozoic-Cenozoic rocks enriched in ancient fossil flora and fauna, as well as due to the tectonic position of the area. The purpose of this study is to determine the main objective of the current geological conditions of stadiality, to compare the leading structuring factors and the mechanisms of neotectogenesis in dislocations in Kaniv unique complex of Geosites. The investigations were provided by structural and morphometric analysis using GIS technology on eastern slope of the Ukrainian Shield. The structural and morphometric method was applied, the essence of which is in search of tectonic structures associated with tectonic movements of the Earth crust. This article shows the relationship of neotectonic movements, and quaternary structures that formed. For the analysis of trials geoinformation technologies (ArcGIS 9.3) were employed. The obtained model included surfaces of paleo- and modern landscapes of different genesis, based on structural and morphometric analysis. The data confirmed the most informative maps are those showing differences of basic surfaces between adjacent orders to quantify the amplitude of vertical movements and identify active local structures for the studied region. The amplitude of tectonic movements of the Earth crust from the Miocene until now has been demonstrated. The change of the local base level of erosion under the influence of the Dnieper River valley and glacial activity as factors for each stage of formation of the Kaniv dislocations has been tracked. Detailed evolution of diapiric structure under various condition of water escape and differentiation of tectonic forces was reconstructed at each stage. Field studies revealed and confirmed the presence of two types of diapiric folds — open and closed. The study of the past will help forecast erosion and sliding activities that endangers and negative impact on the ecological environment and development of agricultural in the area. This research can also serve for a detailed study of the interrelations of sediments and structures that form them belonging to different Quaternary age.

Key words: Morphometric maps, Geological Heritage, Kaniv Dislocation, Quaternary deposits, Neotectonic movements, diapiric folds.

## Introduction

The geological features of the territory have been studied by many of specialists during last 180 years. The main attention was paid to geological, tectonic, stratigraphic paleontological, geomorphological and archaeological peculiarities of the so-called "Kaniv Dislocation" (Fig. 1).

Nowadays, extended and deep ravines cut slopes of the Mountains. The walls of ravines expose Mesozoic — Jurassic (from Bathonian to Callaway), Cretaceous (from Albian to Cenomanian) and Cenozoic (Paleocene, Eocene and Quaternary) sedimentary rocks and geological structures. The Kaniv Mountains (Dislocations) is characterized by a special landscape, the origin of which depends on mysterious factors (tectonic, erosion and continental glaciations). The main factor remains unknown. Perhaps it was pressure of drifting ice mass, reaching the thickness of nearly three kilometers. Critical importance of tectonic movements also is without question.

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One of the constitutive aims was to determine the geological conditions of stadiality. The second — to compare the leading structure-forming factors, which has been achieved though the following tasks:

- to generate structural and morphometric maps and perform a spatial analysis of the datum and vertex surfaces using GIS technology;
- to conduct geological and geomorphological field studies for interpreting morphometric data;
- to carry out a comprehensive analysis of geological data and records of structural and morphometric studies.

The ravines of the region show many objects of geological diversity, some of which represented Geosites of national level. The objects are used to teach geology and geomorphology to students. We took part in the geological practice of first-year students many times. This is how our interest in these problems has arisen.

## Problem statement

The Kaniv State Natural Reserve is located on the territory of the Kaniv Mountains (Hills). The hills of Chernecha, Knyazha (221.2 m) and Maryina Gora (224.4 m) are distinguished in the area. There is also the grave of Taras Shevchenko and museum located on the Chernecha hill. Thanks to the staff of Kaniv State Natural Reserve diverse of plant and animal populations are preserved and being studied. Unique Kaniv glacial dislocations cannot be overlooked in terms of their scientific value. Dislocated Mesozoic and Cenozoic sediment rocks are exposed there. The rocks include many species of fossils fauna and flora of the Mesozoic [9] and Cenozoic ages [11, 14]. The tectonic structure of the region has been a matter of scientific discussion for many years [2, 5]. The origin of "Kaniv dislocations" remains a question. Rock dislocations and sedimentary cover, including folds and nape-thrust structures, are the reason for their distinct geology. "Kaniv Dislocations" clearly differ from adjacent territories by their distinct landscape and unique structure. Tectonic Geosites are the most effective reflection of endogenic processes of the region.

The place is quite impressive and it is an excellent locality for rest and vacations of Kyiv National Taras Shevchenko University in special zone of the reserve. Special trails on the territory of the Reserve are adopted for carrying out practical training of diverse-specialty students from Kyiv Taras Shevchenko National University too (Fig. 2–6).

General analysis of spatial and temporal patterns of the terrain within the Dnieper region proves the multifactorial nature of its formation, but the most important is the issue of priority of each of the factors and their interdependence in certain circumstances, with different combinations of lithological and stratigraphical conditions of the territory, tectonic processes, geomorphological structure, hydrogeological situation, etc. Obviously, solving the above-mentioned problems requires many methods; however, the informational content of each is limited due to the complexity of the structure of the region and its multistage evolution.

The tectonic structure of Kaniv region in recent times is extremely complex, what has been reflected in its ground features to some extent. Considering the fact that the terrain is an integral reflection of neotectonic movements, denudation processes and local geological factors, a detailed study of the relief becomes an effective means of determining neotectogenesis.

This was the reason for the involvement of the structural and morphometric methods, which has been developed by V. Filosofov [3] and used by many researchers to analyze the terrain with respect to its oil-and-gas potential and the search of tectonic structures.

Since these processes have somehow been manifested in the relief of the area, in order to handle some unsolved issues of current tectonics in Kaniv region, the structural and morphometric method was used that enabled us to determine the value of uncompensated crustal movements and denudation level value, to measure the amplitude of relief altitude change, investigate crustal movements, erosion and denudation processes at particular stages of current tectonics stepwise manner. Morphometric maps permitted us to identify not only the tectonic structure marked on the Earth's surface but also deep, hidden local and regional landforms (Fig. 7).

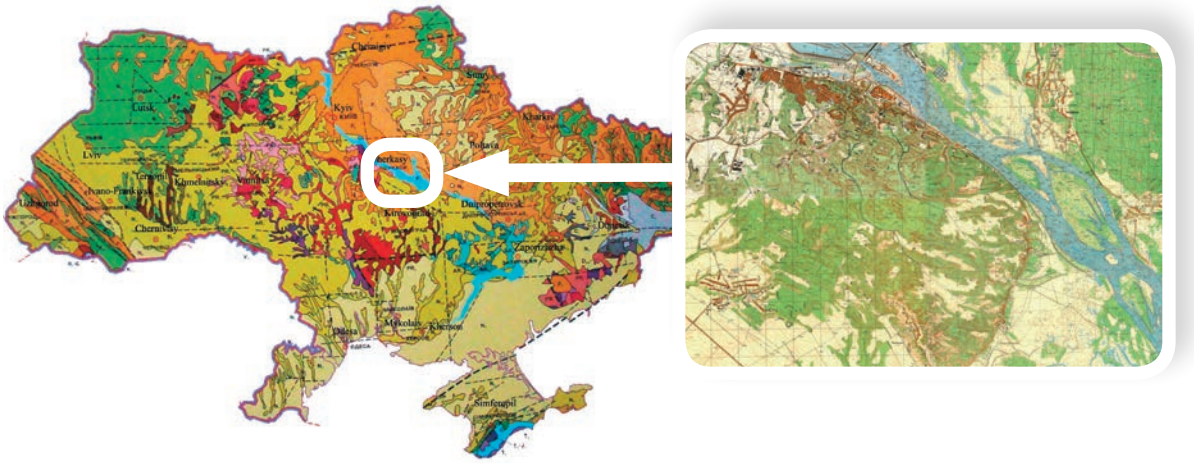

Fig. 1. Geological map of Ukraine. The place of investigations is marked in white square.

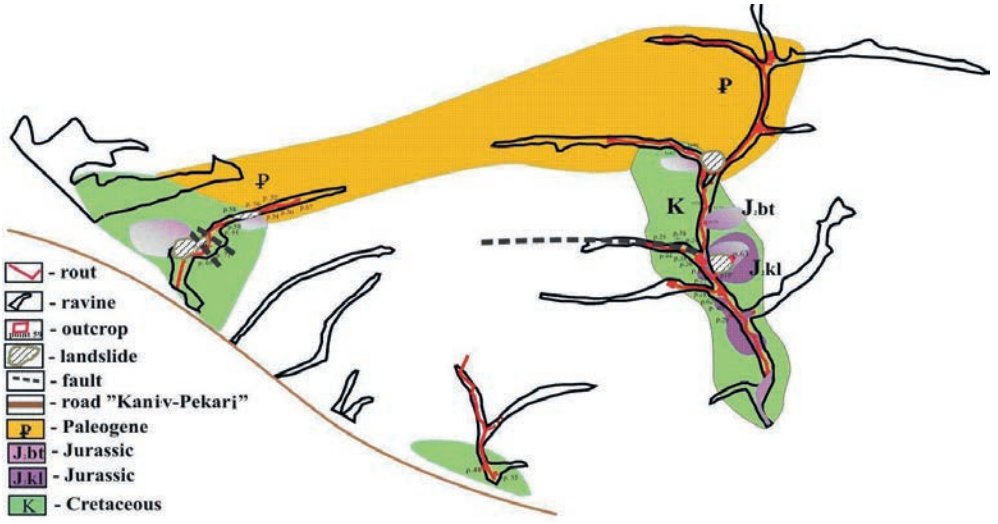


Fig. 2. Students geological practice Polygon of Kyiv Taras Shevchenko National University.

Fig. 3. The outdoor lecture to introducing geological feature of Kaniv Dislocations before trail along ravines.

Fig. 4. A red granite bolder Scandinavian origin from till washed by river on the beach of Kaniv water-storage basin.

Fig. 5. An outcrop of Quaternary till near the lower reaches of Kostyanets Ravine.

Fig. 6. The block of Trakhtemiriv sandstone on the beach of Kaniv water-storage basin washed by waves from deposits of Bouchak local series.

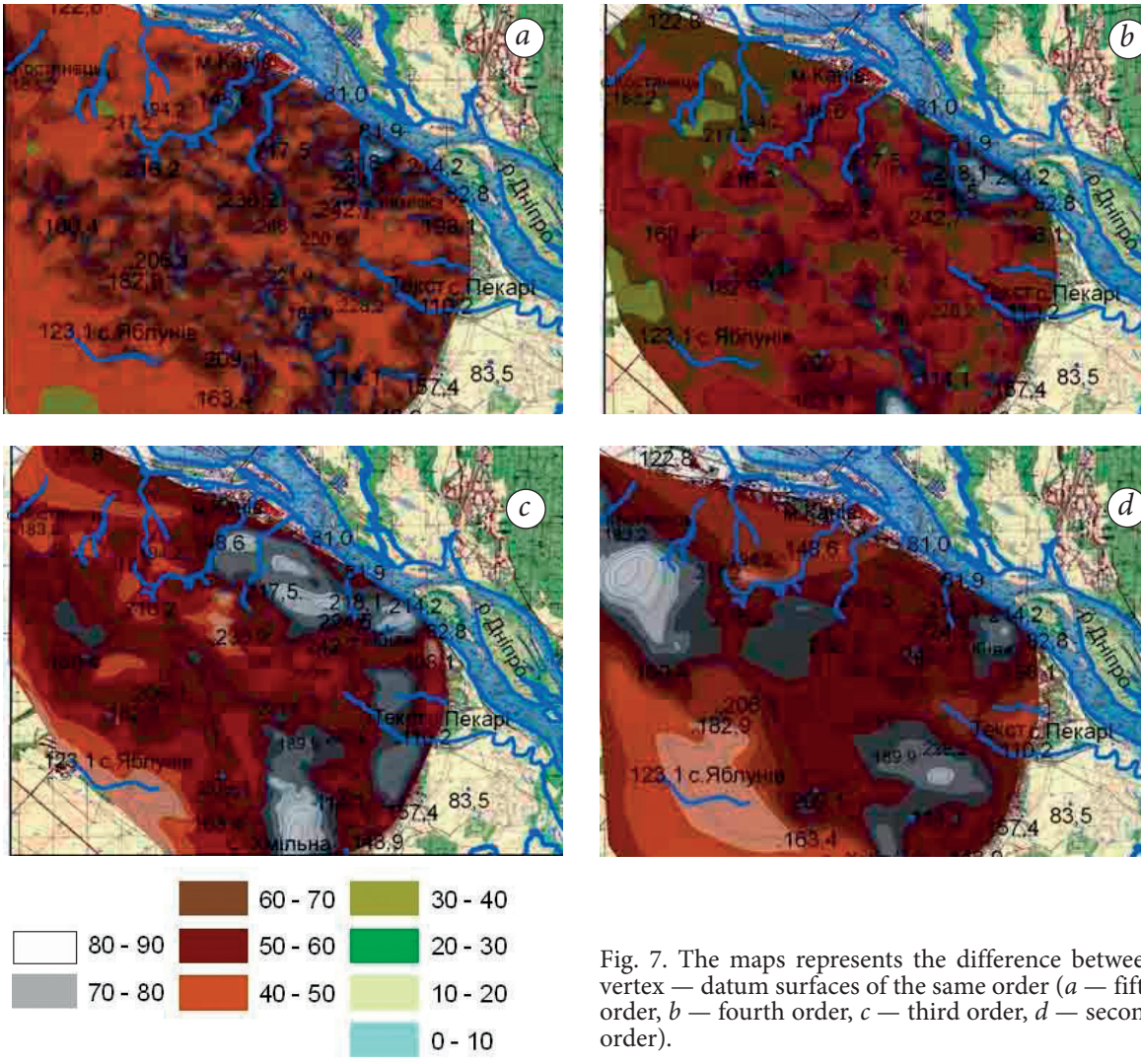


Fig. 7. The maps represents the difference between vertex — datum surfaces of the same order (*a* — fifth order, *b* — fourth order, *c* — third order, *d* — second order).

Fig. 8. Diapiric folds recorded on morphometric maps.

## Methodology of GIS based structural and morphometric maps

The morphometric method is one of the geomorphological methods that studies the quantitative characteristics of the forms of the Earth's surface and different-scale tectonic structures and detects vertical crustal movements. It is a tool to identify the genetic link between geomorphological and tectonic processes, between land forms and the Earth crust structures [3].

The research on terrain and its morphogenetic characteristics called for the Geological Information System, in particular ArcGIS 9.3 (ESRI) software and its specialized modules with powerful functionality of the general spatial analysis, map-metric constructions, transformation and analysis of isolating and grid surfaces and space-time modeling [6].

The study of Kaniv Dislocation terrains and the structure of diverse morphometric maps required a relational geological database, which contained an integrated mapping and attributive information about multi-level valleys and inflows, and other various surface reliefs. Autonomous object classes, classes of spatial objects, relationship classes and attribute domains according to general principles of constructing similar databases have been used for constructing this geological database and comprising the set of object classes [4]. Whole series of morphometric maps and large-scale topographic maps of the studied area have been vectored in order to distinguish the relevant morphological components.

## Study of the structural and morphological maps

A Triangulated Irregular Network (TIN) model was used in the construction and analysis of datum and vertex valley surfaces, which is 3-dimensional data (benchmarks) at the nodes of an irregular triangular mesh. TIN is a surface that reflects the change of the specified characteristics. The TIN-model of the terrain is a polyhedral surface — irregular mesh of triangles with initial geodetic points as their vertices and points of metric of structural lines and squares filled with constant value.

The TIN has been constructed using a specialized Spatial Analyst module to convert vector themes of isolines (basic and hypsometric) into a raster format and to benefit from available analytical facilities of grid analysis: creating surfaces, buffering of spatial objects, etc. [1]. An interpolation of surfaces has been performed by different interpolation methods — backward weighted distances and spine (creating surfaces with minimal curvature). Software facilities of specialized modules allowed us to compare the difference in elevation between the vertices of each TIN face with respective horizontal distances [12].

As a result of the structural and morphometric analysis within the studied area, seven orders of vertex surface and datum surface of five orders of magnitude have been built. A detailed analysis of morphology enabled us to reveal stages of Kaniv Dnieper morphogenesis [16]. The functionality of 3D Analyst and Spatial Analyst specialized modules were also used to further analytical operations to implement the grid analysis. In particular, the statistical analysis of constructed morphometric surfaces allows obtaining data on the maximum and minimum altitude, as well as their distribution and standard deviation.

The recent and current movements of the Earth's crust and other structures formed because of these movements, and maps showing the differences between datum, vertex and datum-vertex surfaces were thus constructed. Distinctions of datum surfaces by graphical subtraction of the datum surface of higher order (fourth, fifth etc.) from the surface of the earlier (second, third) order were drawn.

Five maps of distinctions of vertex surfaces, three maps of distinctions of datum surfaces and four maps of differences vertex — datum surfaces have been obtained. Differences between the surfaces are both positive and negative. Positive differences indicate the elevation of the Earth's surface, and negative differences occur when the surface was lowering down. The same effect results from downward movement the lowering and uplifting of the erosion base level, and occurs due to some other factors of the terrain formation [15].

## Recent movements and their morphometric layout

The tectonic stage has been marked by a total change in the sign of tectonic movements of the whole area. Continental period of the relief formation began during the Neogene. Discordant oscillatory movements of individual blocks were recorded against a general uplift of the Ukrainian shield. Meanwhile, Trakhtemiriv-Bouchak and Kaniv blocks were recorded as horsts (ridge-fault blocks), while Troshchin, Pereyaslav and Cherkassy blocks — as grabens. The latter have been lowered in preice age creating the Pereyaslav and Cherkassy depressions, which have been filled up by Quaternary sediment layers with thicknesses of 40–60 m [10]. As for a larger territory, maximum uplifts occurred in the second half of the Oligocene and Miocene Ages. Evidence of this is on the structural and morphometric map of seventh order vertex surface with a 70 m high amplitude. These movements have been differentiated according to recent structural elements that have different developmental trends. During the next Pliocene epoch, the prevailing trend was towards downturn movements complicated by higher-order impulses with lower amplitude and period. It is proved by the vertex area of sixth order with 30 m high amplitude. Later in the Pleistocene Epoch uplifts prevailed, but with smaller rhythms and shorter periods and smaller amplitudes of tectonic movements, which are reflected in the terraced levels [7].

During the Quaternary history of geological development and relief formation in the Kaniv region, the leading role is played not only by differential tectonic movements, but also by the Dnieper glacier, which has altered the structure of the sedimentary strata, forming laminar-thrust diapiric folds and patterns. In some ravines, large diapiric folds were formed by alluvial sands and forced-out of Cenomanian sandstones were recorded.

Quaternary sediments are common almost everywhere except for steep slopes of river valleys, gullies and ravines, where more ancient rocks are exposed. Their thickness varies from minimal to 100–150 m in valley slopes over deepening areas, but on average, it reaches 10–15 m [13]. The Kaniv Dislocations area, which was undergoing tectonic changes at that time, as evidenced by maps with differences in fifth orders, the average oscillatory movement's amplitude amounted to 76–85 m, resulting in the denudation of Kiev, Kharkiv and Poltava suites and colored clays, with height in exceeding 67 m. Later, the denudated plain has been transformed into a floodplain due to the slowdown of ascending movements, which are indicated in the map of data differences of vertex — datum surface of fourth order with amplitude exceeding 65 m.

Morphometric maps of fifth order datum and vertex surfaces reflect the ribbon-like tuberous, poorly dissected terrain of the Kaniv Dislocation with 70 m high amplitude.

By the Middle Quaternary, the advancement of the glacier has been followed by significant transformations of the relief, caused by tectonic uplifts and ductile deformations of argillaceous rocks. Structural and morphometric maps showing differences of the fourth order datum and vertex surfaces reveal crustal movements within a small area recorded the amplitude of differential displacements from 20 to 85 m. In terms of physical properties, the rocks at the time when shifts developed were ductile, moist with melt water from advancing glacier, overlapped by relatively hard rocks, resulting in double-sliding structures. It was the map of difference of forth order datum surface with positive indicators from 33 to 55 m which depicted the areas with the largest double-sliding structures of injective arch. The pattern of the difference of fourth order vertex surface of isolines reflects erosion activities in the preglacial phase of the Dnieper glaciations; lowland terrain has been dissected by glacier melt water. At that time the over-deepening of the Dnieper valley started and Shevchenko depression was formed, as evidenced by the map of fourth order data surfaces with a minimum height of 95 m, which is considered the local erosion base level.

The Dnieper Glacier covered the Dnieper Valley without blocking watersheds completely, only flooding beds, dampening Jurassic clays with glacial and waters from Dnieper and Ross Rivers. Having run into low mountains, the glacier changed their shape, plowing wide depression valleys, and has moved parts of sheets and ramps as erratic blocks through already dampened soft clay. According to fourth-order vertex surface, the moving glacier divided ancient relief from the height of 100 m, and bent the area in the south-west, forming diapiric structures (Fig. 8). The upper right bank of the Ross

River has been similarly affected, with the only difference that it stretched across the glacier's movement. As a result, a stratal valley and IV over-flood plain terrace on the Dnieper River and Dnieper upland were deformed.

A continuous cover of debris had not been discovered in the area, moraine deposits occur only in the Kaniv block sections. The map of differences of fourth-order vertex surface recorded diverse moraine sediments in low areas with negative differences. They have been recorded on the slopes of the region's peripheral zones, particularly in Kostyanets and Dunaiets Ravines and the towns of Knyazha Hill, Khmilna and the Yabluniv Villages. We must emphasize that Sections of the Kaniv Dislocation are unique in Ukraine. There is a single place where Jurassic and Cretaceous deposits are exposed in complexes of diapiric folds. In the cliff-forming sides of the Kostyanets Ravine from the top to bottom along its main course fold-nappes and anticline diapiric folds with Middle Jurassic Callovian clays in the core are distinguished. The folds and diaper limbs are composed of rocks of Cenomanian Stage, Bouchak and Kaniv Regional Series. The same sections are repeated in all folds. Numerous faults also occur along the ravines. A good example of the Bouchak Series in the Kostyanets artisanal quarry, where quarried white quarzitic sands contain lenses of coaliferous clay and interbeds of sandstones enriched in mollusk shells.

Tectonic nappes and diapiric folds in Kostyanets Ravine are unique tectonic structures of not completely clear origin. Hence, the Geosite is of great scientific value, which has been explored by structural morphometric methods.

Glacier-affected terrain suffered from erosion. An extensive network of cloughs formed as observed on the maps of the third-order datum surfaces. Negative differences correspond to degraded areas where drift sediments have been deposited, recorded by geological sections of the studied area (for example the "Melanchyn Potik" Ravine).

The direction of ice movement was determined by the fall in upthrow faults and the sketch of the structural and morphological maps that bent in the southeastern direction. Besides the main upthrusts in the dislocation area, one could see numerous faults and fissures, proved by the map of valley orders and the neotectonic pattern of faults and fissures.

Loess and loess loam with fossil soils become widespread in Late Quaternary under arid climate. These sediments cover the watershed areas, slopes and plains of ancient terraces. Within the dislocation area their sections are incomplete, indicating accumulative smoothing with a minimum height of 100 m as recorded on morphometric maps of second-order vertex and datum surfaces.

Further epeirogenesis in the Holocene age records erosion processes that continue to the present, and have created deep ravines, representing the history of the formation of Kaniv Mountains. Erosion processes at all stages have been accompanied by vigorous landslide activities, the results of which have become characteristic of Kaniv Region.

## Conclusions

The "Kaniv dislocation" is a complex geomorphological and stratigraphic, paleontological and tectonic Geosite, studied through the past two centuries.

The use of the structural and morphometric methods allowed the refining of the most recent tectonic evolution of the Middle Dnieper area. The formation of an overthrust imbricate structure has been traced. We have reproduced the paleoglaciological situation and mode of development of the filler clay diapiric folds. The tectonic evolution of the Kaniv dislocations has been reconstructed. In the most recent and contemporary stages of the area development five stages have been identified. The established intensity of neotectonic processes has varied, and the associated structure formation is local. Along with exfoliation-related tectonic structures, buried anticlinal folds were found. Based on compiled data, the morphometric tectonic scheme of local structures and faults revealed more than forty local uplift of the oscillation amplitudes relief heights of 20 m to 105 m, which forms area from 125 $m^2$ to 750 $m^2$. Among these, 15 anticlinal folds with different amplitudes and sizes were identified.

A number of geological objects have been investigated: faults, outcrops and barrages of Quaternary, Eocene, Jurassic and Cretaceous ages. This data allowed the following their endogenous and exogenous origin and predicting their further development.

Many Geosites of the "Kaniv Dislocation" are not protected by law because of lack of legal status (except those located on the territory of Kaniv nature reserve). This leads to their destruction and disappearance. The "Kaniv Dislocation" has great scientific value and requires protection. Nevertheless, sand mining in the quarry has almost eliminated the Bouchak Series stratum even in the protected the Geosite "Kostyanets Jar" [8].

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**Дослідження сучасних рухів у геосайтах «Канівських дислокацій» з використанням ГІС. — Тустановська, Л., Гриценко, В.** — Геологічне вивчення Канівських дислокацій було розпочато ще Ф. Дюбуа де Монпере (1832) і є актуальним на сьогодні. Цей район є важливою геолого-геоморфологічною, тектоно-стратиграфічною, палеонтологічною та археологічною пам'яткою. Всі геологічні та біологічні об'єкти охороняються Канівським національним заповідником. Унікальна тектонічна будова цього району. Окрім цього, тут на денну поверхню виходять дислоковані мезозойсько-кайнозойські відклади, які місцями багаті викопними рештками давньої флори і фауни. Метою даного дослідження було визначення геологічних умов стадіальності, порівняння основних структуроутворюючих факторів та механізму неотектогенезу Канівських дислокацій. Для цього застосовано структурно-морфометричний метод, що полягає у пошуках структур, пов'язаних з тектонічними рухами. У статті показано взаємозв'язок неотектонічних рухів, четвертинних відкладів та структур, які ними утворені. Дослідження було проведено із залученням геоінформаційних технологій (ArcGIS 9.3). А саме отримано моделі різногенетичних поверхонь давнього та сучасного рельєфу. На основі структурно-морфометричного аналізу підтверджено найвищу інформативність карт різниць базисних поверхонь між суміжними порядками для кількісної оцінки амплітуди вертикальних рухів та виявлення локальних активних структур досліджуваного регіону. З'ясовано амплітуди тектонічних рухів земної кори з міоцену дотепер. Досліджено зміну місцевого базису ерозії долини Дніпра під впливом епейрогенічних рухів та льодовикового фактора на кожній стадії формування Канівських дислокацій. Простежено детальну еволюцію діапірових структур під впливом обводнення та диференціації тектонічних сил на кожній стадії. Виділено та підтверджено польовими дослідженнями два типи діапірових структур — відкриті та закриті. Вивчення останніх дасть змогу попередити та спрогнозувати ерозійну та зсувну діяльність, що руйнує унікальну геологічну пам'ятку «Канівські дислокації», а також негативно впливає на екологічну обстановку району та на розвиток сільського господарства. Дослідження можуть слугувати також для детального вивчення співвідношень різновікових товщ з четвертинними відкладами та структурами що їх утворюють.

Ключові слова: морфометричні карти, геологічна спадщина, Канівські дислокації, четвертинні відклади, неотектонічні рухи, діапіри.

**Исследование современных движений в геосайтах «Каневских дислокаций» с использованием ГИС. — Тустановская, Л., Гриценко, В. —** Геологическое изучение Каневских дислокаций было начато еще Ф. Дюбуа де Монпере (1832) и до сих пор является актуальным. Этот район важен как геолого-геоморфологическая, тектоно-стратиграфическая, палеонтологическая и археологическая достопримечательность. Все геологические и биологические объекты охраняются Каневским национальным заповедником. Уникальность этого района состоит в том, что здесь на дневную поверхность выходят дислоцированные мезозойско-кайнозойские породы, обогащенные окаменевшими остатками древней флоры и фауны. Необычны и тектонические движения района. Целью данного исследования являлось определение геологических условий стадийности, сравнение основных структурообразующих факторов и механизма неотектогенеза Каневских дислокаций. Был применен структурно-морфометрических метод, суть которого заключается в поисках структур, связанных с тектоническими движениями. В статье показана взаимосвязь четвертичных отложений и структур, вызванная неотектоническими движениями. Для анализа были привлечены геоинформационные технологии (ArcGIS 9.3). Получены модели древних и современных поверхностей рельефа разного происхождения. На основе структурно-морфометрического анализа подтверждена высокая информативность карт разностей базисных поверхностей между смежными порядками для количественной оценки амплитуд вертикальных движений и выявления локальных активных структур для исследуемого региона. Получены амплитуды тектонических движений земной коры с миоцена до современности. Прослежены изменения местного базиса эрозии долины Днепр под влиянием эпейрогеничных движений и ледникового фактора на каждой стадии формирования Каневских дислокаций. Прослежена детальная эволюция диапировых структур под влиянием различного обводнения и дифференциации тектонических сил на каждой стадии. Выделены и подтверждены полевыми исследованиями два типа диапировых структур — открытые и закрытые. Изучение последних позволит спрогнозировать и предупредить проявления эрозионной и оползневой деятельности, которые разрушают уникальную геологическую памятку «Каневские дислокации», негативно влияет на экологическую обстановку района, а также на развитие сельского хозяйства. Исследования могут служить также для детального изучения соотношений разновозрастных толщ с четвертичными отложениями и структурами ими образуемыми.

Ключевые слова: морфометрические карты, геологическое наследие, Каневские дислокации, четвертичные отложения, неотектонические движения, диапиры.

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