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ANALYSIS OF TECTONIC DEFORMATIONS DYNAMICS ON THE EXAMPLE OF THE AREA OF THE SOUTH-WEST WING OF KALMIUS-TORETSK KETTLE HOLE

[1]Bezruchko K.A., [1]Diachenko N.A., [2]Diachenko A.S.

[1]Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine, [2]National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute»

АНАЛІЗ ДІНАМИКИ ТЕКТОНІЧНИХ ДЕФОРМАЦІЙ НА ПРИКЛАДІ ПЛОЩІ ПІВДЕННО-ЗАХІДНОЇ ЧАСТИНИ КАЛЬМІУС-ТОРЕЦЬКОЇ УЛОГОВИНИ

[1]Безручко К.А., [1]Д'яченко Н.О., [1]Д'яченко А.С.

[1]Інститут геотехнічної механіки ім. М.С. Полякова НАН України, [2]Національний технічний університет України "КПІ імені Ігоря Сікорського"

АНАЛИЗ ДИНАМИКИ ТЕКТОНИЧЕСКИХ ДЕФОРМАЦИЙ НА ПРИМЕРЕ ПЛОЩАДИ ЮГО-ЗАПАДНОЙ ЧАСТИ КАЛЬМИУС-ТОРЕЦКОЙ КОТЛОВИНЫ

[1]Безручко К.А., [1]Дьяченко Н.А., [1]Дьяченко А.С.

[1]Институт геотехнической механики им. Н.С. Полякова НАН Украины, [2]Национальный технический университет Украины "КПИ имени Игоря Сикорского"

Annotation. The article presents analysis results in the reconstruction of the tectonic conditions dynamics for the formation of local plicative deformations and rupturing under conditions of the research both the macrostructure and its local separation using the example of the southwestern area of Kalmius-Toretska kettle-hole in the Donetsk basin. Authors applied the scientific cognition method, representing a sequence of actions to establish structural links between variables and constant elements of the Investigational tectonic system, based on statistical and mathematical methods of analysis. The characteristics of the anticlinal structure formation in the studied area - fields of the "Butivska" mine were obtained. It was revealed that the initial horizontal attitude of rocks of the studied area was changed by a monoclinal attitude with a north-western dip and a north-east strike. Afterwards, under the conditions of tectonic near latitudinal compression and near meridional tension, anticlinal folding was formed. Then, under the influence of shear fields when the deformation mode was enhanced, a compression duplex was formed within which local echelon folding and fracture was formed - Oktiabrskyi fault No.1. Maps of local structures from the polynomial of the 1st order to the highest orders with a fairly large degree of generalization, as the trend surface approaches the real geological surface, show the stages of formation and development of tectonics of the region and essentially they are a phased reconstruction of the tectonic deformations dynamics. The proposed method of consistently studying the trend surfaces of polynomials of various degrees (from the 1st and above) can be successfully applied to the reconstruction of the tectonic development of various regions. Moreover, in each individual case, the size of the area being analyzed and the degree of generalization should be chosen depending on the characteristics and complexity of the tectonic structure of a particular region and the operating objectives.

Keywords: the macrostructure, the system analysis, the polynomial, local structures, compression duplexes.

Introduction. The most important task of modern tectonics from the point of view of applied geological research (gas generation, oil generation, ore formation, etc.) is to study the dynamics of the deformation process in the rock strata, which lead to the formation of tectonic structures. The nature of the deformations of any genesis and the conditions for their occurrence are investigated by structural analysis methods – one of the major methods of tectonic research, which is based on the studying the morphology of structures. However, morphological classification without identifying the causes and conditions of structural forms is only a formal description. Any method can be applied both to local areas of the mountain massif and to a large area

of the whole region. The major and most difficult task is the right dividing of the studied geological volume (macrostructure) for the researching the location regularities of its individual tectonic elements in space and chronology of their formation. The choice of the scale in tectonic block dividing is important especially when solving the tasks of specifying the local sections of the rocks in order to search, for example, coal methane accumulation zones. In the current negative situation in the energy sector in Ukraine, this problem has become the greatest relevance. Meanwhile, it is quite obvious that a local area of methane accumulation can be identified only based on knowledge of the causes and mechanism of tectogenesis of the tectonic unit being analyzed, ideas about the genesis and the nature of mining processes occurring in the massif and using modern methods of computer analysis of field data on the base of their mathematical processing.

The most important task of modern tectonics from the point of view of applied geological research (gas generation, oil generation, ore formation, etc.) is to study the dynamics of the deformation process in the rock strata, which lead to the formation of tectonic structures. The nature of the deformations of any genesis and the conditions for their occurrence are investigated by structuralanalysis methods – one of the major methods of tectonic research, which is based on the studying the morphology of structures. However, morphological classification without identifying the causes and conditions of structural forms is only a formal description. Any method can be applied both to local areas of the mountain massif and to a large area of the whole region. The major and most difficult task is the right dividing of the studied geological volume (macrostructure) for the researching the location regularities of its individual tectonic elements in space and chronology of their formation. The choice of the scale in tectonic block dividing is important especially when solving the tasks of specifying the local sections of the rocks in order to search, for example, coal methane accumulation zones. In the current negative situation in the energy sector in Ukraine, this problem has become the greatest relevance. Meanwhile, it is quite obvious that a local area of methane accumulation can be identified only based on knowledge of the causes and mechanism of tectogenesis of the tectonic unit being analyzed, ideas about the genesis and the nature of mining processes occurring in the massif and using modern methods of computer analysis of field data on the base of their mathematical processing.

Cumulative numerous research results of structural forms of the Earth crust in various scales enable to affirm that there is a close relationship between the formation of various structural forms. Any studied structure can be considered as homogeneous one in relation to a certain structural element, providing that within its boundaries the mutual movement of individual sections (parts) does not cause a change in the entire structure. But if the dimension of the smallest movable segment is more than half of the entire part of the structure under consideration, then this part is already heterogeneous [1]. The issue remains open about what can be as dimension indicatorof a tectonic surface when identifying the relationship between the formation of various structural forms of a homogeneous and heterogeneous structure in a rock massif. In 1965 year R. Adler et al. [2] suggested introducing a “scale of

significance" that depends on the sizes of the tectonic surface, whether they are a local fracture, a tectonicblock, or a tectonic plate. Consequently, depending on the nature of tectonic surfaces, it is possible to make both more fractional and less fractional dissection of them. In this case, the most important requirement for the research is the combined use in statistics of directions and attributes in the "volume" of space, i.e. not only in horizontal planes but also in vertical ones.The precondition is the system analysis [3] of statistical observations of homogeneous, i.e. structurally homogeneous zones, and heterogeneous ones in the course of the study of the possible emergence of the tectonic system. Interest in system representations is manifested not only as a convenient generalizing concept, but alsoas a means of problem statement with great uncertainty.

Purpose. Analysis of the reconstruction of the tectonic conditions dynamics for the formation of local plicative deformations and rupturing in the conditions of the research of both the macrostructure and its local division into components using the example of the area in the south-western Kalmius-Toretsk kettle hole, the Donetsk Basin.

Methods. To solve the posed task when studying the emergence of a tectonic system (macrostructure), methods of structural and system analysis and mathematical processing of statistically grounded geological data were used. In particular, the methods of trend–analysis and gradient descent were used, which allow using mathematical methods, by removing the regional background, to identify local inhomogeneities of the hypsometric surfaces of the seams. For the construction of cartograms, polynomials of the first degree and higher orders (up to the 5th inclusive) were calculated, allowing to dynamically isolate secondary structures that complicate the monoclinal slopes of the more significant structures. When applying software tools for mathematical processing of operational field data both local areas of a tectonic unit (the coal bed in a hanging and lying wings of a tectonic fracture) and macrostructure (mining allotment as a whole) were taken for analysis. In the research authors uses a scientific method of knowledge, representing a sequence of actions upon the ascertaining of structural links between variables and permanent elements of the tectonic system under study, based on statistical and mathematical methods of analysis.

Results and discussion. Let us consider the problem under study using the example of the section of the southwestern wing in the Kalmius-Toretsk kettle hole, in particular, the northern part of the Donetsk-Makiivka geological industrial region (DMR) on the area of the "Butivska" mine field. The extensive geological and tectonic analysis of this area, as well as a prognosis of local zones of methane concentration of the coal bed n1, is presented in papers [4, 5]. The authors carried out a structural analysis withinthe mine field, during which they considered the latter as a combination of several tectonic elements - the block of the hanging wing of the Oktiabrskyi fault No.1 and, accordingly, the lying one, thus having divided the original tectonic structure into two blocks (Fig. 1, a) The boundary of the selected blocks, in this reconstruction at the formation process dynamics of the identified two structural noses, determination of their homo- or heterogeneity, and, accordingly, the

identification of causal relationships between the identified and confirmed as a result of operational work in the mine, local zones of methane accumulation. To achieve the purpose in the work, the scale of statistical generalization was changed, i.e. the area of the analyzed surface, increased the case, is the Oktiabrskyi fault No.1. Regarding to the proposed approach, the structural analysis of the bed hypsometry (the construction of the approximate mathematical surface (trend) of the bed hypsometry, the construction of residual surfaces (local structures, as a result of the difference between the approximating and the original real surface) was carried out separately for each block (Fig. 1, b). Based on the obtained results on the deviation of the bed hypsometry n_1 from the approximating surface (a map of local coal bed structures) within the mine field, two tectonic structures (eastern and western) like structural nose were identified [6]. The first is located in the eastern part of the mine field (to the East of the Oktiabrskyi fault No. 1) between the Oktiabrskyi fault No.1 and the Panteleimonivskyi fault, the second is to the West of the Oktiabrskyi fault No.1 (Fig. 2, b). At the same time, their long axes are elongated along Oktiabrskyi fault No.1 and oriented along the strike of rocks for the western structure and at an angle of approximately 45° to the strike of rocks for the eastern. Short axes of the marked structures, respectively, are perpendicular to the Oktiabrskyi fault.

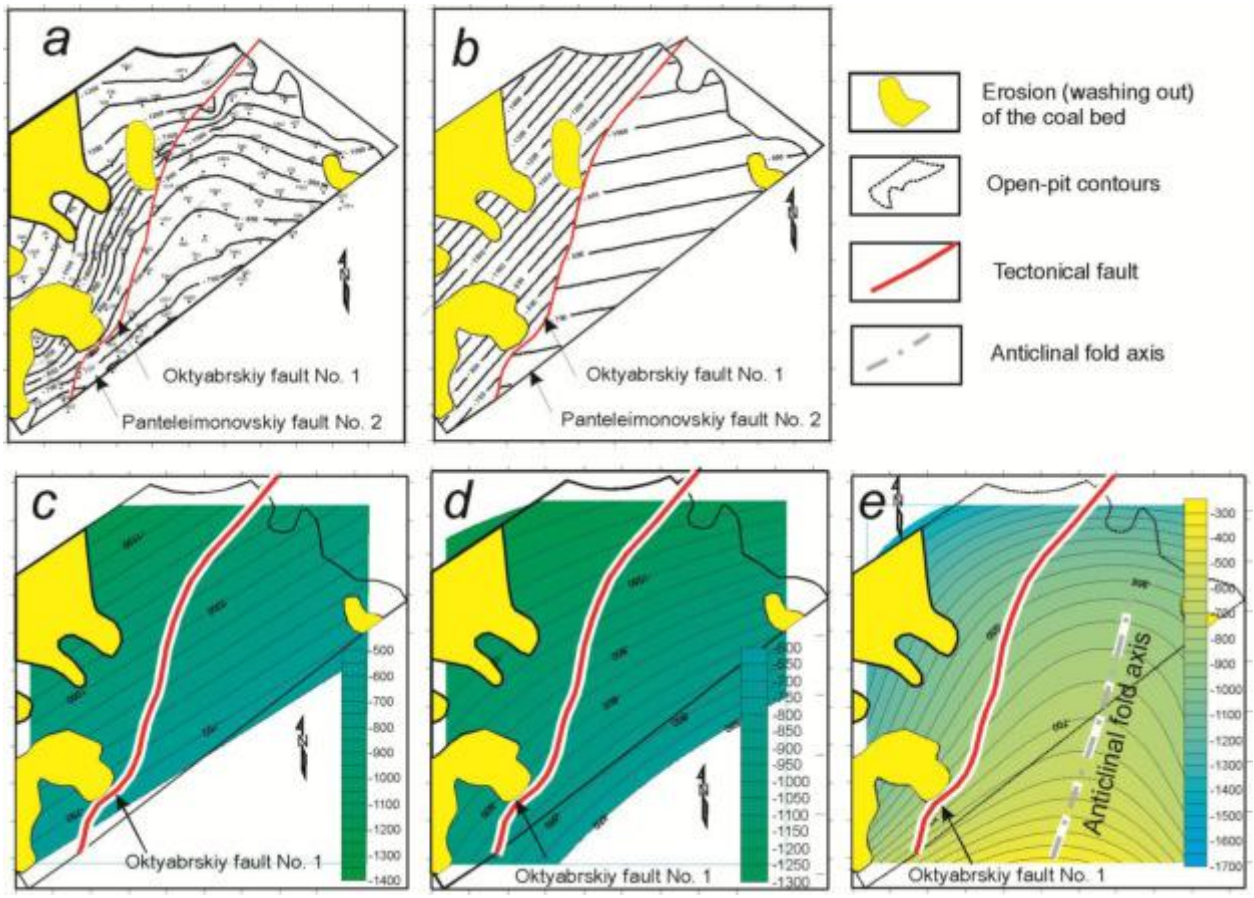

Figure 1 – The hypsometric plan of the coal bed n_1 within the "Butivska" mine (a); trend of the 1st order (b) for the hanging and lying wings [5]; the trend of the 1-2-5th orders for the whole structure of the coal bed n1 within the mine (c, d, e), respectively

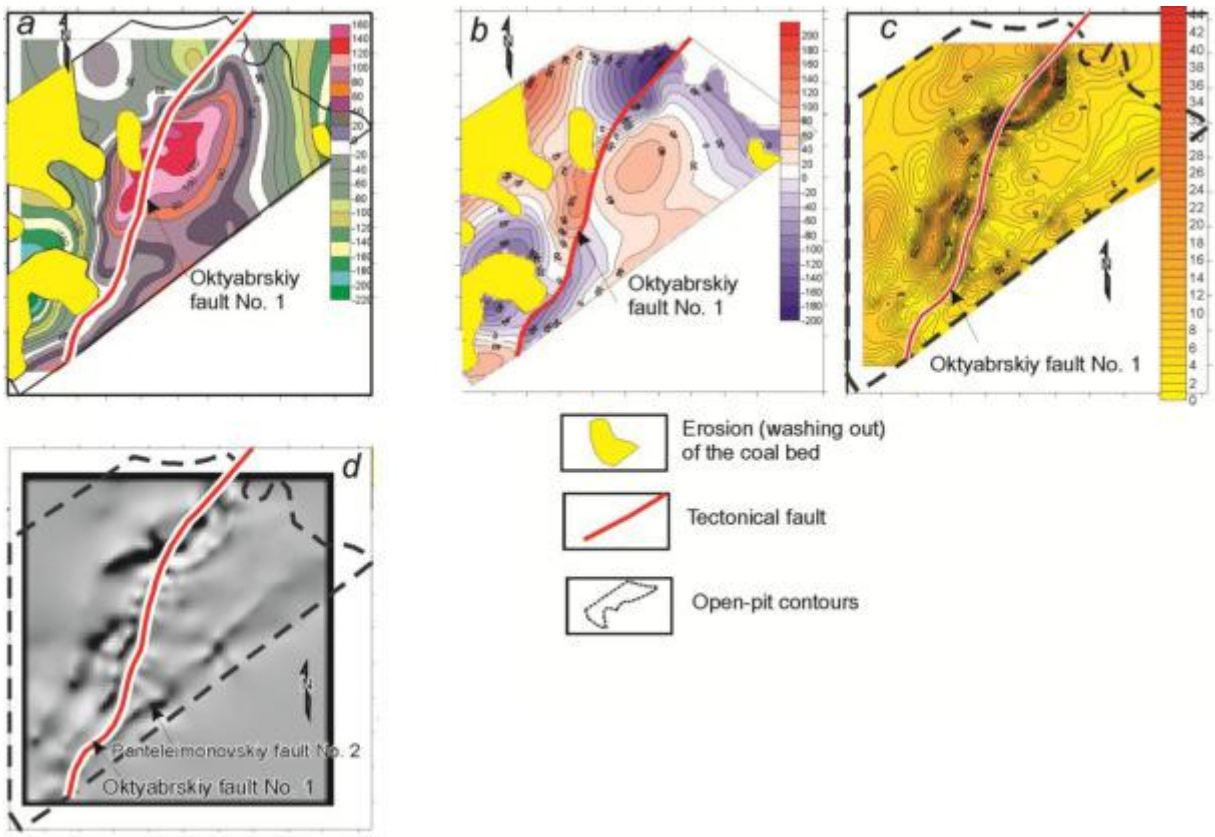

Figure 2 – Selected local structures of the 5th order within the "Butivska" mine field, obtained by conducting structural analysis of the coal bed n1 for the entire analyzed tectonic area (a); local structures of the 1st order for the hanging and lying wings [5] (b); results of the gradient analysis of the tectonic area of the coal bed n1 (c, d)

Using the indicated approach, there is no possibility: a phased degree of the polynomial (Fig. 1, d) and the methods of gradient analysis of structured surfaces was involved (Fig. 2, c, d). Rocks for the western structure and at an angle of approximately 45° to the strike of rocks for the eastern. Short axes of the marked structures, respectively, are perpendicular to the Oktiabrskyi fault. Using the indicated approach, there is no possibility: a phased reconstruction at the formation process dynamics of the identified two structural noses, determination of their homo- or heterogeneity, and, accordingly, the identification of causal relationships between the identified and confirmed as a result of operational work in the mine, local zones of methane accumulation. To achieve the purpose in the work, the scale of statistical generalization was changed, i.e. the area of the analyzed surface, increased the degree of the polynomial (Fig. 1, d) and the methods of gradient analysis of structured surfaces was involved (Fig. 2, c, d).

The final (sought-for) result – is a cartogram of the surface residue (Fig. 2, a) between the actual surface (hypsometry) of the coal bed n_1 (Fig. 1, a) and the mathematical trend of the 5th order (Fig. 1, e) suggests that the accumulation of the original material and forming the attitude surface of the coal bed n1 within the mine field, which took place under horizontal attitude, was changed by a monoclinal attitude with a northwest dip and a northeast strike. Subsequently, under the conditions of tectonic near-latitudinal compression (σ_3= 290–300º) and near-meridian

tension (σ_1= 20–30º), an anticlinal fold is formed, the axis of which is coaxial with the strike of the current position of the Oktiabrskyi fault No. 1.

Then, at bending in the seam, the substance is redistributed in such a way that it moves from bendings with a relatively small radius of curvature to bendings with a bigger radius of curvature, forming local warping structures (Fig. 2, a) an area of the increased values of the surface residue. Subsequently, during the shear, under the impact of oppositely directed forces, the echelon folding is formed, which is tilted in the direction of the active forces action and adjoined to the shear surface at an angle close to 45º. On the southern wing of the anticline is formed the fracture of the Oktiabrskyi fault No.1.

Most often, it is safe to say how the fold was formed, only on the basis of the researcher's ideas about its formation and must usually use by different models based on theoretical constructions and the results of physical modeling. That is why the same fold can be classified in different ways. If we consider the folds from the point of view of the applied forces orientation with respect to the seam, they can be divided into folds of longitudinal bending and the transverse one. Folds of the 1st class emergence as a result of tangential squeeze of the seams, the forces acting in the folding of the longitudinal bending are compression, and the deformations undergone by the body is deformations of compression, and each seam in separate parts undergoes deformations of tension and compression – in others. The mechanism of the formation of the formed paragenesis in the tectonic structures is apparently due to sheardisplacements along the deep shear with the formation of a compression fracture anticline on the southern wing. Especially in contrast, tectonic structures are fixed on the cartograms of the surface residue gradient module of the fifth order (Fig. 2, c, d).

The obtained characteristics of the formation conditions of the anticlinal structure are fully matche with the results of work regarding the conditions and features of the DMR tectonics formation [7, 8, 9]. It is proved that in the region the main tectonic structure, controlling the accumulations of free gas, is the zone of shear dislocations development and have the completely regular orientation (Fig. 3): fractures, presented by faults C* and folding F* (strike azimuth 27º±4º), being formed perpendicular to the axis of shortening (σ_1*: 297º± 4º) and parallel to the axis of elongation (σ_3*: 27º±4º).

The obtained results indicate on the formation of the tectonic structures of the “Butivska” mine in the shear dislocation mode and closely match the development interpretation of the regional right shear zone of the north-east strike (strike azimuth 245º± 5º) and its peripheral areas in (DMR) [7, 10], The indicated zone was a precondition of a “starter mechanism” in the formation of shears. R_1*, R_2*, P*, tension cracks and throws T*, faults C* and folds F* (on the peripheral adjacent areas) when the deformation mode is strengthened in the central part of the zone in the block, bounded from the northwest by Kalininskyi fault, from the East - by Sofiivskyi one and from the South by the Providance system. The effect of Z-shaped refraction entered into force in the changing the orientations of the main violations within the central part of the shear zone and its peripheral boundary sections (see Fig. 3, b). For the boundary sections of the deformable strip due to the edge effect, with

increasing strip dimensions in the direction of the shear axis, the role and impact of normal shear stresses σ_1*-σ_3* on the axial zone decreases.

In fact, within the "Butivska" mine, a specific compression duplex was formed [8] – the fault "scaly" plate, within which local folds Fand fractures of the "fault" type Care formed, and which practically disappear or flatten out of the coal beds boundaries. Compression duplexes occur due to a local change in the position of the tension axis from subhorizontal to subvertical ones while maintaining the subhorizontal position of the compression axis.

Localization of compression duplexes in coalbeds significantly affects the formation of prerequisites for gas accumulation manifestations in coal beds, because they are as gathering barriers on the migration way of gaseous hydrocarbons from deep horizons [8].

The objectivity of the obtained results and conclusions confirms the factthat when nalyzing the above papers [7-10], the block of "Butivska" mine was not included as an object of the research and not considered at all.

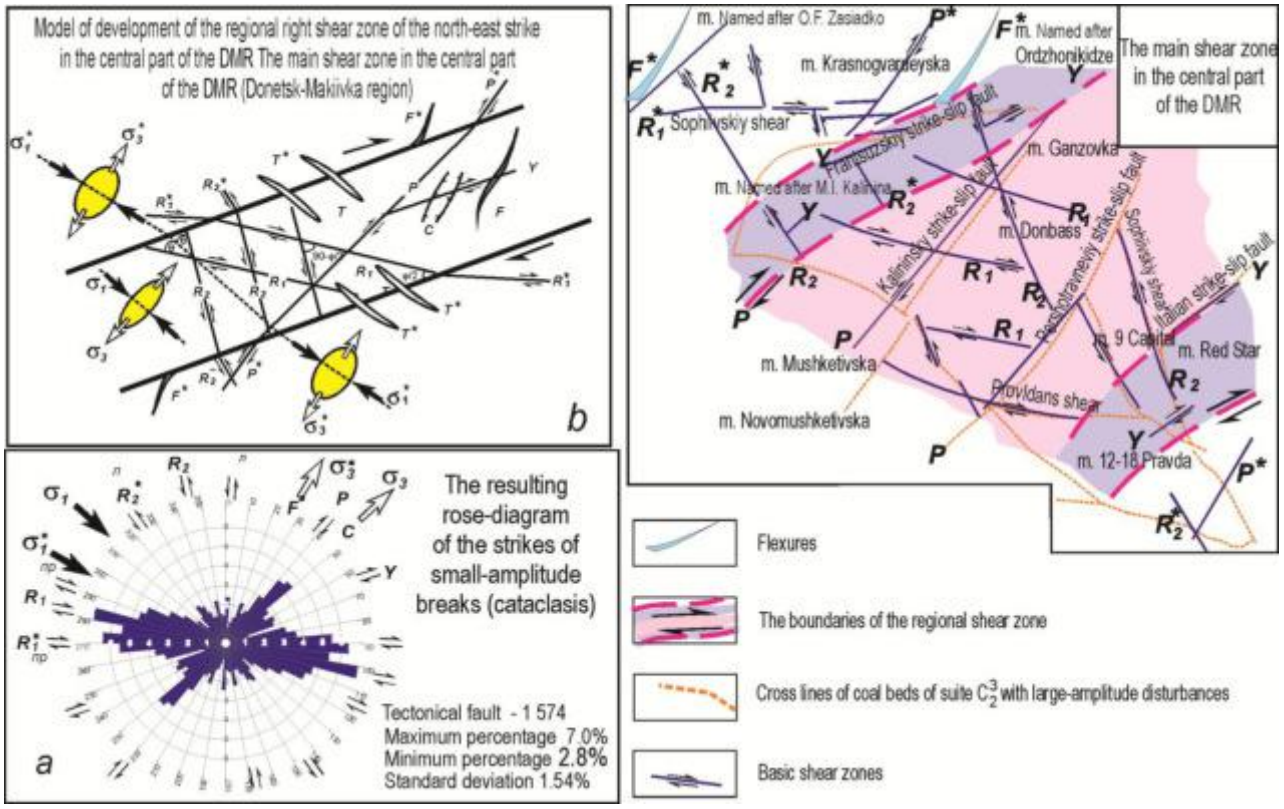

Figure 3 – The main shear zone in the central part of the DMR with the interpretation of movements upon the main section fractures [7]. On the inset map a – strike interpretation of small-amplitude tectonic disturbances (synthetic, antithetic shears, stretch cracks, folds and faults) on the total rose-diagram; b - model of development of the main diagonal shear zone

Conclusions.

1. Analysis of the reconstruction of the tectonic conditions dynamics for the formation of local tectonic deformations allowed us tracing the history of the geological development of the area under study, in the part of its tectonic evolution. The initial horizontal rocks attitude of the area under study — the "Butivska" mine

field on the section of the southwestern wing at the Kalmius-Toretsk kettle hole of the Donetsk basin, was changed by a monoclinal attitude with a north-western dip and a north-east strike. Subsequently, under conditions of tectonic near latitudinal compression and near meridional tension, the anticlinal fold is formed, the axis of which extends from the south-south-west to the northnorth-east. Then, under the influence of shear fields of stresses, when the deformation mode is strengthened due to a local change in the position of the tension axis from subhorizontal to subvertical while maintaining the subhorizontal position of the compression axis within the "Butivska" mine boundaries, a compression duplex is formed - a fault "scaly" plate, within which a local echelon folding, which is inclined towards the action of active forces and approaches the shear surface at an angle close to 45º and on the southern wing of the anticline fracture of the "fault" type - Oktyabrskyi fault No. 1.

2. Maps of local structures from the polynomial of the 1st order to the highest orders with a fairly large degree of generalization, as the trend surface approaches the real geological surface, show the stages of formation and development of tectonics of the region and essentially they are a phased reconstruction of the tectonic deformations dynamics.

3. The proposed method of consistently studying the trend surfaces of polynomials of various degrees (from the 1st and above) can be successfully applied to the reconstruction of the tectonic development of various regions. Moreover, in each individual case, the size of the area being analyzed and the degree of generalization should be chosen depending on the characteristics and complexity of the tectonic structure of a particular region and the operating objectives.

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About the authors

Bezruchko Kostiantyn Andriiovych, Doctor of Geology Sciences (D. Sc), Senior Researcher, Head of Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine (IGTM, NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Diachenko Natalia Oleksandrivna, Candidate of Geological Sciences (Ph.D.), Senior Researcher, Senior Researcher in the Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine (IGTM, NAS of Ukraine), Dnipro, Ukraine, natalidyachenko1969@gmail.com

Diachenko Anna Serhiivna, Student, Institute for Applied Systems Analysis (IIASA), National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute» (KPI, Ukrainian Ministry of Education and Science), Kyiv, Ukraine aniyamaniya1@gmail.com

Про авторів

Безручко Костянтин Андрійович, доктор геологічних наук, старший науковий співробітник, завідувач відділу геології вугільних родовищ великих глибин, Інститут геотехнічної механіки ім. М.С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна gvrvg@meta.ua

Д'яченко Наталя Олександрівна, кандидат геологічних наук, старший науковий співробітник, старший науковий співробітник відділу геології вугільних родовищ великих глибин, Інститут геотехнічної механіки ім. М.С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна, natalidyachenko1969@gmail.com

Д'яченко Анна Сергіївна, студентка, Інститут прикладного системного аналізу (ІПСА), Національний технічний університет України "КПІ імені Ігоря Сікорського" (КПІ, МОН України), Київ, Україна, aniyamaniya1@gmail.com

Анотація. У статті наведені результати порівняльного аналізу палеотектонічних реконструкцій динаміки тектонічних умов формування локальних плікативних деформацій і розривоутворення в умовах дослідження як макроструктури, так і її локального поділу на прикладі ділянки Кальміус-Торецької улоговини. Застосований науковий метод пізнання, що представляє послідовність дій по встановленню структурних зв'язків між змінними й постійними елементами досліджуваної тектонічної системи, заснований на статистичних і математичних методах аналізу. У дослідженнях отримані характеристики умов формування антиклінальної структури досліджуваної площі – поля шахти «Бутовська». Виявлено, що початкове горизонтальне залягання порід досліджуваної площі змінилося моноклінальним заляганням з північно-західним падінням і північно-східним простяганням. Згодом, в умовах тектонічного близширотного стискування й близмеридіонального розтягнення сформувалася антиклінальна складчастість. Потім, під впливом зсувних полів напруг при посиленні деформаційного режиму, сформувався дуплекс стиску в межах якого формується локальна кулісоподібна складчастість та розрив «Октябрський» насув № 1. Карти локальних структур від поліному 1-го порядку до більш вищих порядків, при досить великому ступені узагальнення, у міру наближення поверхні тренда до реальної геологічної поверхні, відбивають етапи формування й розвитку тектоніки регіону та по суті є поетапною реконструкцією динаміки тектонічних деформацій. Запропонований метод послідовного вивчення поверхонь тренда поліномів різних ступенів (від 1-го й вище) може бути успішно застосований для реконструкції тектонічного розвитку різних регіонів. Крім того, в кожному окремому випадку розмір аналізованої області та ступінь узагальнення повинні вибиратися в залежності від характеристик і складності тектонічної структури конкретного регіону і операційних цілей.

Ключові слова: макроструктура, системний аналіз, поліном, локальна структура, дуплекс стиску.

Аннотация. В статье приведены результаты сравнительного анализа палеотектонических реконструкций динамики тектонических условий формирования локальных пликативных деформаций и разрывообразования в условиях исследования как макроструктуры, так и ее локального разделения на примере участка. Применен научный метод познания, представляющий последовательность действий по установлению структурных связей между переменными и постоянными элементами исследуемой тектонической системы, основанный на статистических и математических методах анализа. Получены характеристики условий формирования антиклинальной структуры изучаемой площади – поля шахты «Бутовская». Выявлено, что изначальное горизонтальное залегание пород изучаемой площади сменилось моноклинальным залеганием с северо-западным падением и северо-восточным простиранием. Впоследствии, в условиях тектонического близширотного сжатия и близмеридионального растяжения сформировалась антиклинальная складчатость. Затем, под воздействием сдвиговых полей напряжений при усилении деформационного режима сформировался дуплекс сжатия, в пределах которого формируется локальная кулисообразная складчатость и разрыв Октябрьский надвиг № 1. Карты локальных структур от полинома 1-го порядка до более высших порядков при достаточно крупной степени обобщения, по мере приближения поверхности тренда к реальной геологической поверхности, отражают этапы формирования и развития тектоники региона и по сути являются поэтапной реконструкцией динамики тектонических деформаций. Предложенный метод последовательного изучения поверхностей тренда полиномов различных степеней (от 1-го и выше) может быть успешно применен для реконструкции тектонического развития различных регионов. Кроме того, в каждом отдельном случае размер анализируемой области и степень обобщения должны выбираться в зависимости от характеристик и сложности тектонической структуры конкретного региона и операционных целей.

Ключевые слова: макроструктура, системный анализ, полином, локальная структура, дуплекс сжатия.

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