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The relation of the northwestern shelf deep geological structure of the Black Sea with the phenomenon of gas seeps

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Received: 17.12.2019 Received in revised form: 14.01.2020 Accepted: 29.01.2020 **Abstract.** Geophysical model inputs were the results of a survey on an anomalous magnetic field and a gravitational field of the Black Sea's north-western shelf. The geophysical profiles of the complex effective parameter (CEP) are calculated and graphed. Complex effective parameter characterizes the relationship between the effective densities

and the magnetization by their spatial distribution. Effective parameters (magnetization, density, CEP) were calculated within the study area with their distribution on the optimum depth. The profiles are meridional and parallel to each other, direction of the profiles from south to north. The distance between the profiles is 50 kilometers. The generalized deep structure of the study area was elucidated using the graphed profiles. The distribution of CEP on vertical sections within the shelf zone of the western Black Sea basin emphasizes the position in the space of tectonic elements. That is gives an idea about the nature and structure of the region's lithosphere and their relationship with the spatial distribution of deposits and manifestations of hydrocarbons. Structural and geological interpretation of the CEP profile data was performed. According to the spatial consistency of the correlation by structures, the profiles are conditionally divided into two groups, the western and the eastern. Structural differences in profiles are explained by the presence of the Odesa-Sinop fault zone between the groups. According to the results of profiles interpretation and works of previous researchers, paleogeodynamic processes were established. That significantly complicated the geological structure of the Black Sea's north-western shelf. The interpretation of the CEP field distribution gives additional arguments in favour of the Earth crust evolution on the north-western shelf of the Black Sea in the conditions of a passive continental margin with short periods of reverse motions with obligatory subduction due to the activation of rifting, the nature of which is yet to be studied. According to the results of interpretation, the presence of the Earth's crust destruction zone was established. With the help of spatial analysis, the spatial regularities of the gas seeping manifestations with the zone of destruction of the Earth's crust of continental type and sites of rising of the mantle surface are established.

Keywords: gas seeping, geological structure, north-western shelf, Black Sea, depth structure, geophysical model

Зв'язок глибинної геологічної будови північно-західного шельфу Чорного моря з феноменом газових сипів

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Анотація. Вхідними даними геофізичного моделювання стали результати зйомки аномального магнітного поля та гравітаційного поля північно-західного шельфу Чорного моря. Побудовано геофізичні профілі КЕП – комплексного ефективного параметру, що характеризує взаємозв'язок ефективних густини і намагнічування за їх розподілом у просторі. Ефективні параметри (намагнічування, густина, КЕП) обчислювались у рамках території досліджень з розподілом на оптимальну глибину. Профілі є меридіональними, напрямок профілів з півдня на північ, та паралельними один одному. Відстань між профілями склала 50 кілометрів. За допомогою побудованих профілів з'ясовано узагальнену глибинну структурну будову району досліджень. Розподіл КЕП в вертикальних розрізах в межах шельфової зони західно-чорноморської западини підкреслює положення у просторі окремих тектонічних структур, дає уявлення про характер і будову літосфери регіону та їх взаємозв'язок з просторовим розподілом родовищ та проявів вуглеводнів. Проведено структурно-геологічну інтерпретацію даних профілів КЕП. За просторовою узгодженістю кореляції по структурам профілі умовно розділені на дві групи західну та східну. Структурні відмінності по профілям пояснюються наявністю між групами Одесько-Синопської розломної зони. За результатами інтерпретації профілів та роботами попередніх дослідників встановлено палеогеодинамічні процеси, що суттєво ускладнили структурно-геологічну будову Північно-західного моря. Інтерпретація розподілу полів КЕП дає додаткові аргументи на користь розвитку земної кори північно-західного шельфу Чорного моря в умовах пасивної континентальної окраїни з короткочасними періодами реверсних рухів з обов'язковою субдукцією завдяки

активізації рифтогенезу, природу якого ще належить вивчати. За результатами інтерпретації встановлено наявність зони деструкції земної кори. За допомогою просторового аналізу встановлено просторові закономірності проявів глибинної дегазації із зоною деструкції кори континентального типу та ділянок підйому поверхні мантії.

Ключові слова: газові сипи, геологічна будова, північно-західний шельф, Чорне море, глибинна будова, геофізична модель

Introduction. The combination of properties of the Black Sea natural gas seepage phenomenon and its magnitude have aroused great interest among experts in Ukraine, Black Sea and Western European countries. Seep gases contain 80-99 percent of methane. The emissions of these gases can be very powerful; therefore, they can be considered as a hydrocarbon resource, for the production of which there is no need to drill wells.

Previous researchers have collected a large amount of information (Egorov, Artemov&Gulin, 2011; Shnyukov, Kobolev&Pasynkov, 2013), that allows gas emissions to be connected with the geological features of the Black Sea bottom and, as a consequence, connected with deep active faults, which gives grounds to link the nature of the origin of methane with deep faults, as with sources. This is also indicated by the restoration of reservoir pressure in already developed hydrocarbon deposits. Today there is no single viewpoint on this feature. Two hypotheses compete for explaining the methane origin in seeps: biological methane origin and the migratory methane origin. The magnitude of gas seeps and the lack of their confinement to the places of probable organic materials' accumulation cast doubt on the dominance of the methane genesis biological hypothesis. Analysis of the chemical and isotopic gas composition reinforces the notion that this methane gas is likely to have a predominantly deep origin.(Lukin, 2003)

Geological and geophysical studies of the Black Sea gas seeps' distribution zones, including the northwest shelf, are being carried out in Ukraine since the significance of such works is obvious.

Data and research methods. A long-term geophysical study of the geological structure for the territory of Ukraine and analysis of the data obtained in the course of the performed studies indicate its complex deep structure, which is reflected in geophysical fields.But numerous highly qualified researchers have studied the distribution of geological heterogeneities mainly on the research area (on the horizontal plane). Vertical geological heterogeneities were detected only by seismic and geoelectric studies. Such studies are performed on separate profiles, or in threedimensional version on very local sites. Therefore, this study uses a different approach to the study of territory -a technique that was developed in 2001-2015 in the Department of Regional Geophysical Research of UkrSGRI. This technique is used to study the depth

of the structure of a network of vertical sections along a regular network of profiles, as well as sections that are calculated along with regional seismic profiles and international arbitrary geo-traverse. The analysis covers not only sections of physical parameters by each of the geophysical methods but also their transformants. The most informative of them in the study of deep geological structure is CEP - a complex effective parameter. It characterizes the relationship between effective densities and the magnetization of their distribution in space. The distribution of CEP in vertical sections and horizontal sections characterizes the possible geological structure of the study area, that is, allows one to determine the probable geometrical parameters and positions in the space of individual structures and their relationship with adjacent structures both in the plane of the section or slice and at different hypsometric levels of the lithosphere. The initial data are anomalous magnetic and gravitational fields. The distribution of effective magnetization, density, and CEP are calculated with help the methods developed at KazVIRG (Koval, Priezzhev, 1983).

Effective parameters (magnetization, density, CEP) are calculated within the study area with distribution at optimum depth. The result of the calculations is cubes of parameter distribution, where each node of the cube in the coordinates X, Y, Z corresponds to a certain value of the parameter. The plane along an arbitrary direction, vertical horizontal or inclined, can cut each cube. Analysis of the CEP distribution on the horizontal plane of any depth of immersion, as well as the corresponding analysis of vertical sections, allows one to perform interpretation of the sections in conjunction with the data of other geophysical methods (for example: DSZ, MTZ) and geological data. The results of interpretation are the material that allows us to build a spatial (threedimensional) geological-geophysical model of the study area (its first, initial version, which can be refined and adjusted in the future).

The authors calculated, constructed and analyzed vertical sections of a complex effective parameter of the meridional direction, the distance between which is 50 km (sec.625-650 Fig. 1, 2) and whose directions coincide with the grid of the Gauss-Kruger coordinate system-42 (6250000-6500000 respectively). The sections were analyzed by the researchers in conjunction with pre-built maps, which helped to fill the scheme of the deep geological structure for

the region with some information. The profiles in blue (negative CEP value) correspond to the suboceanic lithosphere, red colour (positive CEP value) corresponds to the continental-type lithosphere, and the white line (zero CEP value) is the conditional boundary of earth crust types.

Key aspects of interpretation of CEP profiles. In connection with the discovery of hydrocarbon deposits, fixed displays numerous gas flares in the north - western shelf of the Black Sea, researchers have recently given increased attention to the study of the Earth's crust and upper mantle of this region

Within the framework of the scientific tasks, the researchers ofUkrSGRI constructed six meridional profiles of the complex effective parameter (CEP), calculated according to the gravitational and magnetic fields with the distance of 50 km between them and a step along the 5 km profiles (Figs. 1, 2). In the north, the profiles cover the southern part of the Ukrainian Shield, composed of Early Cambrian rocks, and continue through the Southern Ukrainian Monoclinic and ended in the northwestern shelf of the Black Sea within the economic zone of Ukraine. The western profile extends slightly to the east of the Danube Delta, the eastern one passes through the Tarkhankut Peninsula in the northwest of Crimea.

Black Sea, according to the tectonic scheme of the deep structure(Gurskiy, Kruglov, 2007;Samsonov, Chumak, 2004), the foundation is the Epihercynian Scythian plate (SP) with the continental type of lithosphere. Late Paleozoic sediments with fragments of Baikalids were deformed in the Triassic, and since the Jurassic, the Scythian plate represented the area of sediment accumulation in the platform regime. There is some thought about the earlier age of the Scythian plate foundation, and it is regarded as an SEP marginal zone with an Early Cambrian foundation characterized by reduced continental crustal thickness. The dominant tectonic regime of the area in the Late Devonian-Late Jurassic was rifting, which was replaced by opposite movements, the main of which is the closure of the Taurian Basin of the Paleo- Tethys Ocean in the Late Triassic(Gintov, Egorova, Tsvetkova, Bugayenko, Murovskaya, 2014).

The Odessa-Sinop deep fault of the northwestern extension divides the Scythian plate in the study area into the western and eastern parts, which differ in the depth of the basement. To the west of the fault (sections 625-635), the pre-Jurassic formations are abandoned and even reach the bottom (Snake Island), while in the eastern part (ex. 640-650) the surface of the pre-Jurassic rocks is submerged. The analysis of CEP



Fig. 1. The geophysical sections of the complex effective parameter (CEP) for the northwestern shelf of the Black Sea

The northern part of the territory through which the profiles pass is the ancient Eastern European Platform with the corresponding foundation.For the shelf zone of the northwestern depression of the profiles confirms the fact that the eastern and western groups of profiles do not agree on each other at the level of the lithosphere.It is likely that the structure of the lithosphere on the study area may be affected



Fig. 2. Map of the destruction zone distribution of the northwestern shelf continental margin

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by the trans-regional tectonic seam of Kherson-Smolensk, which is displaced by the system of righthand displacements of the Krasnoperekopskaya zone on the southern flank of the Eastern European platform.

The majority of researchers adhere to the point of view of the rifting nature of the Black Sea (Western and Eastern) depressions, which were formed as a result of the continental-type lithosphere expansion. However, for the present, scientists are discussing the causes of rifting. The most common idea is the rise of the mantle diapir (or plume) from the lower mantle proposed by Chekunov A.V. Due to the warming of the continental crust, reducing its viscosity, the formation of convective flows by mantle diapirs, the continental crust began to stretch and open with the formation of a rift, which enters magmatic rocks as mantle derivatives and a new type of oceanic crust was formed. Followers of the asenolithic (plume) concept of oceanic crust formation in the Western Black Sea depression (Kobolev, 2017) have proposed a three-vector form of rifting crustal elongation in the formation of a domed uplift over the mantle diapir. The rest of the geologists see the Black Sea as an arch-basin formed in the rear of the Pontic island arc as a result of rifting that began in the Cretaceous, and even in the Paleogene. Magmatic formations (Fig. 2) are an indicator of geodynamic conditions of the development on the studied territory. Shnyukova K.E. (Shnyukova, 2016) presents the results of petrographic, petrological, geochemical, mineralogical studies of the discovered magmatic rocks underwater exits, especially the Lomonosov submarine massif. Comparison of the above characteristics of the erupted rocks of the Lomonosov submarine massif with magmatic formations known in the Crimea, allowed the author to conclude about the different time of their rooting in different geodynamic conditions. The author argues that in the course of the geological evolution of the study area, several stages of subduction-related magmatism are distinguished, and are of repeated occurrence. The collected data indicates at least two stages of such magmatism: the end of the Middle Jurassic - early Cretaceous and late Cretaceous - Paleogene. Scientists who have studied this region share a common view that the modes of stretching of the crust changed over time in opposite movements, which was accompanied by tectonic dislocations of sedimentary rocks and processes of subduction.

The CEP sections ended in the continental slope within the economic zone of Ukraine and do not extend through the Black Sea depression. The absence of primary data on the gravitational and magnetic fields above the depression does not allow us to analyze the CEP field above the area, where, according to the assumptions of other researchers, the rifting zone is located. The subduction phenomenon that has occurred in the past indirectly indicates the nature of the CEP field in the eastern profiles, which, in our opinion, is related to the processes of continental crust destruction. In addition, the sections (sec. 640-650) exhibit an increased continental-type lithosphere with the keel-like shape, which is underlain by suboceanic crust . This phenomenon may be related to the continental-type cortical tightening due to the A-type paleo-subduction. It should be noted that in the CEP fields of the eastern group of profiles, an elongated negative anomaly is clearly distinguished among the positive field, which has a slight northward slope. This feature can be interpreted as a mega-outlier of the oceanic type crust, over which the gravitational anomaly of the Mountain Crimea and the continental slope adjacent to the west are fixed. The phenomenon of rooting of mantle melt in the weakened zones of the continental-type crust is the characteristic phenomenon during subduction processes. The presence of "mantle rejectors" may indicate paleo-subduction that occurred during the closure of the Tauride basin in the Jurassic under the conditions of an active continental margin (Gintov, Egorova, Tsvetkova, Bugayenko, Murovskaya, 2014; Gurskiy, Kruglov, 2007) with a simultaneous approaching of the Scythian plate sedimentary rock to the outskirts of Eastern European platform. At profile 650 above the projection of the «recluse», underwater deviations of intrusive rocks, which by petrological features are related to islandlike, subduction-related complexes, have been detected (Shnyukova, 2016). According to drilling in the Karkinitsky deflection of lowland Crimea, "volcanic rocks (basaltic tuffs, breccia of lava, andesite-basalts, andesite, and their tuffs) and plutonic analogues of the South Crimean sub-volcanic complex of the Middle Jurassic were discovered above the "body of rocks of mantle origin", which by their petrological nature may be associated with the phenomenon of paleosubduction. Also on the west-south-west shelf of the continued Karkinitsky trough and the northern slope of the Kalomitsky uplift gas-bearing structures in the Mesozoic-Cenozoic shelf deposits were discovered.

In the southern part of the 640-650 profiles, there is an area, which by the nature of the CEP field, is interpreted by authors, as a zone of the continental crust destruction, its extension, and reduction of thickness. The saturation with faults of the dropping type and increased permeability is characterized this geological situation. The zone of degassing of the lower mantle is probably associated with the same zone. On the sections 640-650 in the fields of the complex effective parameter is registered the rising of mantle matter to the depth near 18-20 km (sec. 640). The corresponding form of the CEP field negative anomaly has emphasized this conclusion. The magmatic solutions and deep fluids migrationchannel of is formedabove the apical part of the mantle vault. Numerous manifestations of gas seeps and igneous rocks of the Lomonosov massif (sec. 650) have spatially gravitated to the destruction zone (sec. 635, 640, 645).

For the marine part of the western profile group (625-635), a different character of the CEP field is observed, for which lateral positive and negative anomalies alternate. According to S.S. Krasovsky (Institute of Geophysics of NASU) for this segment of the crust is characterized by an increase in continental-type crust thickness with which the Khmelnytsky-Odessa orthocraton coincides, within which the formation of a granulite-basite layer of crust extends to the surface of the Precambrian section. In the area of the intersection with the sections of the Ukrainian shield crystalline basement rocks, granulite exiting the day surface in the Dniester-Buzshky mega-block correspond to the negative anomalies of the complex parameter (Kirilyuk, 2005).In the shelf zone, the positive and negative anomalies in the upper part of the sections are isometric and elongated, alternating on lateral. The structures (handfuls-grabens) of the underwater part of the Scythian Plate identified in this area according to geological and geophysical data are in good agreement with the anomalies of the CEC field. The uplifts and depressions of the Odesa Black Sea shelf conform to the boundaries of the Scythian plate, and their alternation is typical for shelf zones of the oceans. Numerous manifestations of gas fountains are confined to the outer boundary of the shelf zone, which is traced along the edge of the Northwestern Depression continental slope of the Black Sea. In the rear zone of the gas seeps distribution there are known hydrocarbon deposits (Fig. 2) and potentially promising local antiform formations. The absence of vultures in the eastern part of the Earth's crust destruction zone (sec. 650) near the Crimea is probably associated with volcanism over the subduction zone, which resulted in the formation of Lomonosov submarine massif igneous rocks (Fig. 2). According to the authors, such processes led to the "filling" of cracks in deep faults with igneous rocks and prevented the penetration of deep methane into the discharge zones.

Conclusions. The distribution of CEP in vertical sections within the shelf zone of the Western Black Sea depression emphasizes the spatial position of

individual tectonic structures, gives an idea of the nature and structure of the lithosphere of the region and their relationship with the distribution of hydrocarbon manifestations. The interpretation of the CEP field distribution gives additional arguments for the option of the Black Sea northwestern shelf crust developing in the passive continental margin conditions with short periods of reverse motions with obligatory subduction due to activation of rifting genesis, the nature of which remains to be explored. The spatial relationship of deep degassing manifestations with the continental crust destruction zone and the mantle surface elevation areas is shown.

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