УДК 553.98:550.8(477.52/.6)

S.G. Vakarchuk

LITHOFACIES ANALYSIS TO PREDICT UNCONVENTIONAL HYDROCARBON ACCUMULATIONS IN THE LOWER VISEAN CARBONATE SEQUENCE OF THE DNIEPER-DONETS GRABEN

С.Г. Вакарчук

ЛІТОЛОГО-ФАЦІАЛЬНІ АСПЕКТИ ПРОГНОЗУВАННЯ СКУПЧЕНЬ НЕКОНВЕНЦІЙНИХ ВУГЛЕВОДНІВ У ВІДКЛАДАХ НИЖНЬОВІЗЕЙСЬКОГО КАРБОНАТНОГООГО КОМПЛЕКСУ ДНІПРОВСЬКО-ДОНЕЦЬКОЇ ЗАПАДИНИ

The paper features results of prospective potential assessment for unconventional hydrocarbons in the Lower Visean carbonate sequence of the Dnieper-Donets graben. Spatial development features for prospective rocks within different facies zones of the Lower Visean carbonate sequence are elucidated upon the basis of main criteria to evaluate exploration potential for unconventional hydrocarbons (lithological composition, rock thermal maturity, porosity and permeability, total organic matter content, and depth of occurrence). The role of litho-facies studies for unconventional hydrocarbons prospecting is shown.
Keywords: Dnieper-Donets basin, Lower Visean carbonate sequence, unconventional hydrocarbon, lithology.

У статті наведені результати досліджень перспектив пошуку неконвенційних вуглеводнів у відкладах нижньовізейського карбонатного комплексу Дніпровсько-Донецького грабену. На основі аналізі основних критеріїв оцінки перспектив пошуку неконвенційних вуглеводнів (літологічного складу, ступеня термальної зрілості, фільтраційно-ємнісних властивостей, вмісту органічної речовини, глибини залягання) визначено характер розповсюдження перспективних порід в межах різних фаціальних зон нижньовізейського карбонатного комплексу. Показана роль літолого-фаціальних досліджень при пошуках неконвенційних вуглеводнів.
Ключові слова: Дніпровсько-Донецький басейн, нижньовізейський карбонатний комплекс, нетрадиційні вуглеводнів, літологія.

INTRODUCTION

Successful development of unconventional hydrocarbon resources that took place last 10-15 years in the sedimentary basins of the U.S.A. and Canada gives a possibility to remap hydrocarbon potential of such mature petroleum provinces like the Dnieper-Donets basin (DDB). Previous studies testify that this region can be prospective for shale gas and oil, as well as tight gas and oil in arenaceous and carbonate rocks (Lukin, 2011; Lukin, 2010; Vakarchuk et al., 2012; Vakarchuk et al., 2013; Vakarchuk et al., 2014; Mykhaylov et al., 2014). At that the resources of unconventional hydrocarbons may exceed ones for oil and gas in conventional reservoir rocks (Lukin, 2011; Vakarchuk et al., 2013; Vakarchuk et al., 2014; Mykhaylov et al., 2014). Discovery and development of these unconventional accumulations can actually provide a second wind to development of the Dnieper-Donets petroleum province and significantly increase domestic oil and gas production. One of the prospective plays in this direction is the over Visean carbonate sedimentary rocks that are widely developed within the Dnieper-Donets basin.

UNCONVENTIONALS PROBLEM STATUS QUO

There are many researches devoted to the problem of prediction and prospecting for unconventional hydrocarbons in the Dnieper-Donets basin have been published last years in Ukraine (Lukin, 2011; Lukin, 2010; Vakarchuk et al., 2012; Vakarchuk et al., 2013; Vakarchuk et al., 2014; Mykhaylov et al., 2014). The most comprehensive analysis of this is provided by A.E. Lukin (Lukin, 2011; Lukin, 2010) as well as the monograph series prepared under aegis of Naftogaz of Ukraine National Joint-Stock Company by experts from different research organizations elucidating the studies for unconventional hydrocarbon sources in the sedimentary basins of Ukraine, and DDB in particular (Vakarchuk et al., 2013; Vakarchuk et al., 2014). The above cited publications feature as theoretical as practical issues of prospecting for unconventional hydrocarbons. Specifically, it was substantiated criterial assessment system for shale and tight gas and oil potential in arenaceous and carbonate rocks. Stratigraphic levels, rock sequences and areas prospective for unconventional hydrocarbons development were determined and recommendations for the exploration targeting were formulated. At the same time the problem of unconventional hydrocarbons exploration in the carbonate rocks was secondary priority while detail studying of shale and clastic rocks. Within the framework of those studies the basic criteria of assessment and main stratigraphic levels of carbonate rocks prospective for unconventional hydrocarbons were described yet, however, regulations of spatial development of those prospective sequences were beyond the scope of previous studies. In this connection one

of the most relevant tasks to solve the problem of commercial hydrocarbon potential of tight carbonate and carbonate shale rocks is to outline boundaries of their lateral development and formulate the prerequisites to rank the area studied upon its prospecting potential. A significant role in this process belongs to lithofacies study as shown below.

DATASETS, SAMPLING, AND APPLIED METHODS.

The study is based on results of integrated analysis of stratigraphic, lithofacial, petrophysical and geochemical researches for the Lower Visean carbonate sediments obtained during conventional exploration activity as well special pyrolitic analyses. 270 analyses for petrophysical rock properties, 245 ones for rock thermal maturity, 55 for C_{org} (TOC), 78 for X-ray diffraction, and over 320 descriptions of cores and thin sections from 145 wells were made. Also, to recognize intervals prospective for unconventional hydrocarbons and estimation of their saturation parameters well logs from 25 wells were processed applying special techniques. Delineation of prospective areas and ranking of hydrocarbon potential for each lithofacies zone was performed upon the basis of early developed author's criteria for assessment unconventional hydrocarbon prospecting in the carbonate sequences that were taken using analysis of geological, geophysical, testing and production data from the sedimentary basins of North America (Vakarchuk et al., 2013; Vakarchuk et al., 2014). The main of those criteria are as following: lithological composition – massive grainstones and packstones, re-crystallized biogenic mudstones and wackestones, dolostones; silicified carbonates and cherts as well as hydrocarbopelites; C_{org} over 1%; thermal rock maturity R_o – 0.62 to 0.80 unconventional oil, from R_o 0.80 to 2.5 for unconventional gas; minimal porosity as much as 1,5% for gas and 2% for oil; permeability not less than 0.009 mD for gas and 0.1 mD for oil; net thickness of prospective interval should be more than 25 m for oil and 40 m for gas; depth to exploration target is down to 4500 m.

Prospecting lithofacies settings. Lower Visean carbonate sequence are widely developed over the whole territory of the Dnieper-Donets graben excluding its northwestern part and some localities within the external flank zones where shale carbonate rocks are substituted with terrigenous ones. Carbonate sediments of the Lower Visean sub-stage lie with gap and angular unconformity on different horizons of Tournasian stage, and in some areas of external flank zones lie upon Upper Devonian sediments and Archean-Proterozoic rocks. The sequence is overlaid by clayey-sandy sediments of the Upper Visean sub-stage. Formation of that sequence took place at the open marine settings governing cyclic transgressions in the northwestern direction Most of areal development of the Lower Visean sequence is represented by complex-built formation with alternation of limestones and argillites characterized by significantly various ratio of calcareous and shale rocks in different structural/facies zones. Thickness of the Lower Visean carbonate sequence changes from 20-25 m to 250-300 m. Depth to top of the sequence vary from 1800 to 6100 m in drilled wells.

Upon the result of conducted detail lithological and paleogeographic studies it was evidenced that the Lower Visean carbonate sequence was deposited within lithofacial zones as following: open marine, slope, reefal, shelfal, lagoonal, littoral, and large intrabasinal banks ones (fig. 1) (Vakarchuk, 2003; Lukin and Vakarchuk, 1999).

Open marine facies zone. Sediments of this zone occur in the deepest parts of the Dnieper-Donets basin. These ones are studied most comprehensively within the Sribne and Lokhvitsa depressions as well as northern part of the South External Flank zone in the southeastern part of the graben. Open marine facies zone sediments are represented by black, silicified, irregularly calcareous, bituminous argillites interbedded with thin limestone beds. Limestones are black, bituminous, clayey, silicified, mainly packstones with mudstones. Silicites and hydrocarbopelites are rather widely developed throughout the basin. The paleogeographic restorations demonstrate that deposition of these sediments took place within the open marine facies zone at deepwater setting accompanied by uncompensated subsidence of the sea floor (Vakarchuk, 2003). Lower Visean sediments thickness of his zone vary from 30-40 to70-80 m. Drilled sections reveal the thermal rock maturity ranging from MK_2 to AK_1 stage (R_o – 0.8-2.36) (fig. 1). Within depth interval 3900-4500 m average values of R_o are of 1.05 that corresponds to initial and main window of gas generation (MGW). C_{org} content in the shale carbonates of this zone changes from 2,5 to 11,2%. Kerogen is of III type. Average values of of open porosity for carbonate and shale rocks are 1.0-2.0 % with average porosity less than 0.005 mD. Depth to the sequence in the drilled wells ranges from 3900 to 6100 m.

Issuing from the above criteria shale carbonates of this zone is prospective for unconventional gas with high condensate ratio. The exception is represented by areas of intrabasinal reefs (pinnacles). These are knob-like isolated carbonate build-ups

encircled by shale carbonate sediments (Vakarchuk, 2003). Presence of build-ups of such type is distinctly revealed by drastic increasing of the sequence thickness up to 120-130 m comparing to surrounding background values of 30-50 m. These build-ups do not exceed 1.0-1.5км×2.0-3.0 km in size. They are composed by biohermal limestones with subordinate role of packstones and shales. By this date such pinnacles are known for Kampanska, Pryrichna, Bilychivka conventional hydrocarbon fields.

Large intrabasinal carbonate banks zone. Deposition of these sediments in terms of paleogeography took place within rather large uplifts located in the central part of open marine basin. Results of paleogeographic studies testify that deposition within those areas was compensated contrary to settings of the open marine facies zone. By this date the sediments of intarbasinal banks are recognized in Yablunivka, Rudivka, West Solokha and other fields. Lithologically, the rocks of this facies zone are mainly represented by packstones and grainstones with different shale to carbonate ratio, and quite often by strongly re-crystallized limestones. Sometimes, biohermal varieties occur in the section. These limestones make beds of Вапняки 5-10 to 50-70 мм thick alternating with shale beds of 3-4 to 10-15 m thick.

Rock thermal maturity in the drilled wells changes from $МК_2$ to $АК_1$ (R_o – 0.75-2.3) corresponding in general to MGW (fig. 1). Average values of open porosity fro carbonate rocks is of 2.5-4.5% with permeability below 0.1 mD, and 0.5-2.5% for shaly rocks with permeability below 0.005 mD. C_{orgr}. Content in the carbonate rocks is of 0.8-1.5%, and fro accompanied shaly ones are as much as 1.2-5.6%. Kerogen is of I and II-I types. Depth to sequence top in the drilled wells ranges from 4200 м to almost0 5300 m.

Main exploration prospects in this zone are related to unconventional accumulations in the tight carbonate rocks and adsorbed gas in shale carbonated rocks in the depth down to 4500 m (fig. 1).

Slope facies zone. Sediments of slope facies are represented by rhythmic alternation of carbonate and shale units and characterized by clinoformal occurrence with decreasing of thickness towards the depocenter. Total thickness of the carbonate sequence varies in a broad range from 30-40 m at the toe to 80-90 m at the upper hinge of the slope. Down the dip it is observed substitution of limestones with shales as well as of decreasing of thickness and number of carbonate beds. Slope facies zone as a narrow band rims the depressional zone. Rock thermal maturity in the drilled wells reveals values from $МК_2$ to $МК_4$ (R_o – 0.78-1.2) corresponding in general to MGW initial stage (fig. 1). C_{org} content in the shale carbonates of this zone changes 1.5 to 7.8%. Kerogen is of III type. Average values of open porosity for the carbonate and shale rocks are at 1.5-2.5% with average permeability less than 0.01 mD. Depth to the sequence in the drilled wells varies from 3200 to near 4900 m.

Sedimentary rocks of the slope facies zone are prospective for unconventional gas with high condensate content except of areas deeper than 4500 m (fig. 1).

Reefal facies zone. This zone is characterized by maximum thicknesses and most complete section of the Lower Visean sediments as well as predominance of biohermal varieties in carbonate sequence ranging from 56 to 65% (Vakarchuk, 2003; Lukin and Vakarchuk, 1999). Biohermal rocks of this zone have formed core parts of rather large build-ups of marginal type that along with inter-reefal sediments make the reefal zone. Lithologically inter-reefal sediments are represented by alternation of different clastic limestones, breccia-like limestones (formed due to destruction of the solid skeleton of the marginal build-ups) and shales. Presence of biogenic build-ups of the marginal type is proved by this date for Lypova Dolyna, Perekopivka, Anastasiivka, Ozeryany, Hortytsa, Ignatovka, Zagorany and Movchanivka fields. Thickness of the reefal facies sediments varies from 80 to 70 m within inter-reefal areas and from 150 to 180 m in the central parts of reefal massifs proper.

Rock thermal maturity in the drilled wells changes from $МК_2$ to $МК_3$ (R_o – 0.72-1.15) corresponding in general to beginning of MGW (fig. 1). Open porosity values for the rocks forming central parts of reefal massifs are ranged from 5.5 to 19.5% at permeability varying from 0.1 to 10-40 mD (up to 370 mD for fractured areas). Average values of open porosity for inter-reefal rocks are of 3.5-5.5% at less than 0.05 mD of permeability. C_{org} content for the rocks of the build-ups core part is changed from 0.1 to 0.4%, and for inter-reefal rocks from 0.3 to 0.9%. Kerogen is of III, sometimes of mixed II-III type. Depth to the sequence in the drilled well varies from 2300 to almost 5100 m.

Sediments of this zone are prospective for conventional hydrocarbon accumulations. Some exploration perspectives are related to inter-reefal areas, however, due to their minor acreage they should not be considered as independent exploration targets (fig. 1).

Shelfal facies zone. Shelfal zone sediments are most studies ones because they are penetrated by

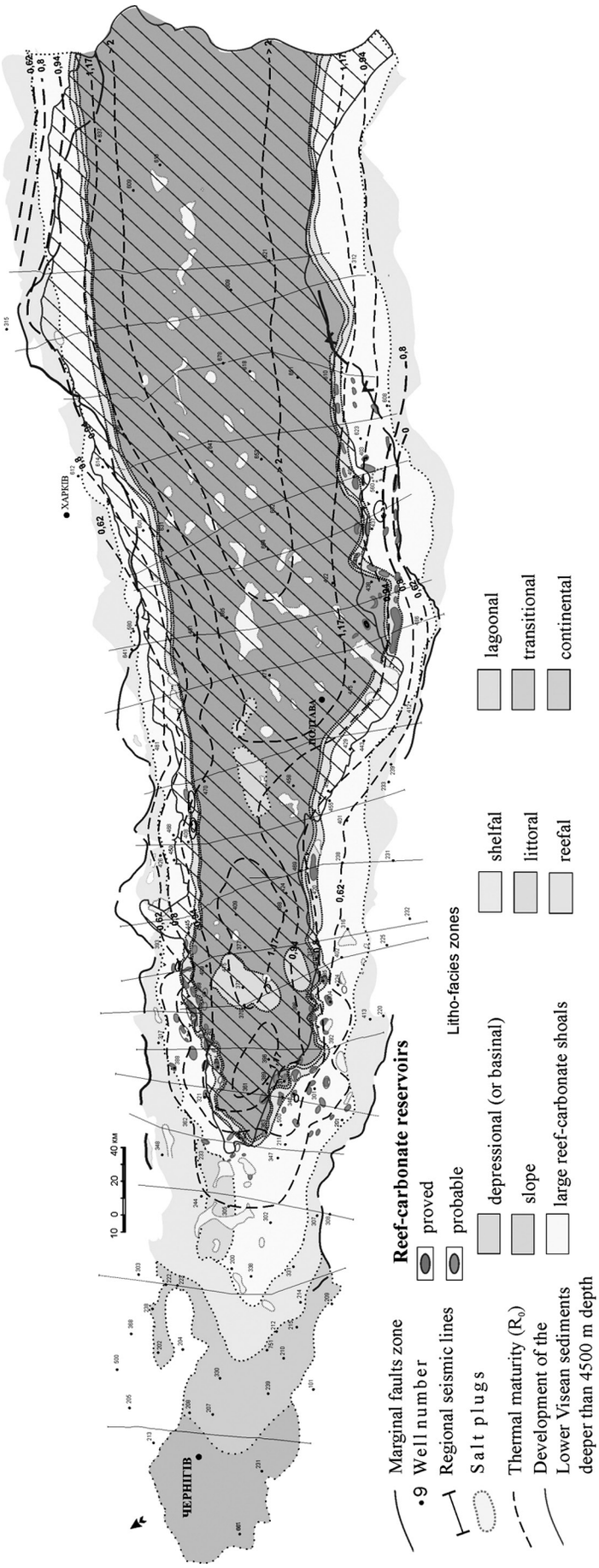

Рис. 1. Літофаціальна карта нижньовізейського карбонатного комплексу Дніпровсько-Донецької западини.
Fig. 1. Lithofacies map of Lower Visean carbonate complex of the Dnieper-Donets graben.

numerous prospecting and exploration wells drilled in different structural zones of the DDB graben. Deposition of those sediments took place at shallow water settings with normal salinity. Lithologically the rocks of this zone are represented by gray and light-gray almost re-crystallized limestones, packstones and grainstones with different shale to carbonate ratio. The limestones occur as separate beds of 20-50 m thick alternating with shales of 1-2 to 8-12 m thick. The most complete sections contain 6-7 individual limestone beds. Top and bottom of the carbonate sequence is of shale predominance as a rule. На окремих ділянках шельфової зони достатньо широкий розвиток отримали невеликі за розмирами біогермні споруди (Vakarchuk, 2003; Lukin and Vakarchuk, 1999). Biohermal bodies of such type have thickness of 20-40 m and occur inside non-reefal carbonate shallow shelf sediments. Lithologically those bioherms are composed by massive, gray dolomitized an almost re-crystallized biomicrites and biosparites, often strongly cavernous and fractured with subordinate role of clay content. Argillites are black, dark-gray and gray, calcareous and occur as rare interbeds of small thickness. Intra-shelfal bioherms contain commercial conventional hydrocarbon reserves in some fields (Selyukhovka, Lychkove, Pereshchepyno, etc.).

Rock thermal maturity in drilled wells varies from PK_3 to MK_4 (R_o – 0.45-1.55) (fig. 1). Average values of open porosity for biohermal facies composing the cores of the build-ups is characterized by 6.0-7.0 % values (for cavernous and fractured verities up to 22%), permeability ranges within 0.05-1.0 mD (вin some cases as much as 146 mD). Average open porosity outside bioherms is 2.5-4.5 %, permeability – 0.005-0.05 mD. C_{opr} content for carbonate rocks composing core of bioherms is 0.1-0.2 %, and 0.5-1.5 % outside of them. Accompanying clayey rocks have a porosity ranging from 0.9 to 3.5%. Kerogen is of II-III types. Depth to target horizons in the drilled wells varies from 1700 to 5500 m.

The results of different prospecting criteria integration for the unconventionals have shown that the most important among them for the shelfal zone rocks is thermal maturity value. Upon this index the territory of carbonate rocks development is subdivided onto three zones: the first one is corresponded to thermally immature rocks (R_o – 0.45-0.6), the second one to rocks mature for liquid hydrocarbons generation (R_o – 0.6-0.8), and third one to rocks mature to generate gaseous hydrocarbons (R_o – 0.8-1.55) (fig. 1). Thus, the last to zones are prospective for unconventional oil and gas exploration, respectively, in tight carbonate rocks.

Littoral facies zone. Littoral sediments are characterized by alternation of biogenic limestone beds with clayey limestones, shales, sandstones and siltstones. In the far northwest the sediments are become more sandy and transferred into terrigenous rocks. Maximum thickness of individual carbonate beds is of 5-8 m and 3-5 m for shaly ones. Rock thermal maturity in the drilled wells is changed from PK_2 to MK_2 (R_o – 0.4-0.8), average values of R_o do not exceed 0.5 (fig. 1). Average values of open porosity for the carbonate and shaly rocks vary from ередні значення 0.5 to 2.0% with permeability less than 0.01-0.03 mD. C_{org} content in the carbonate rocks reaches 0.2-0.3%, and 0.3-0.8% for shaly ones. Kerogen is of I and II-I types. Depth to the sequence in the drilled wells changes from 1100 to near 4000 m.

Taking into account minor thickness of prospective layers, lower thermal maturity and low C_{org} content as well, the sediments of this facies zone are unviable for exploration of unconventional accumulations.

Lagoonal facies zone. Sediments of lagoonal facies have a local development and represented by micro-grained massive limestones with rare, depressed stenohaline fauna and coal shales. Sometimes, dark-gray dolomite interbeds occur in the section. Thickness of this zone sequence is of 10-30 m. Rock thermal maturity in the drilled wells varies from PK_2 to MK_1 (R_o – 0.5-0.65) averaging to 0.55 (fig. 1). Average values of open porosity for the carbonates is 1.0-2.5% with permeability less than 0.01 mD, and 0.5-20% for shaly rocks with permeability below 0.005 mD. C_{org} content in the carbonate rocks is 0.3%, and 0.7% in shales. Kerogen is of II-I type. Depth to sequence in the drilled wells ranges from 2500 to almost 4100 m.

Like for previous zone, the sedimentary rocks of this one are non-promising for exploration of unconventional hydrocarbons.

CONCLUSIONS

Upon the results of conducted studies it is confirmed the presence of sedimentary rocks promising for unconventional hydrocarbons in the Lower Visean carbonate sequence. It is evidenced that main perspectives for unconventional hydrocarbon accumulation exploration should be attributed to two rock types – shale carbonates (adsorbed or shale gas) and tight carbonates (tight gas). Prospective potential of separate facies zones is analyzed and the conclusions are made as following. The Lower Visean rocks of open marine basin and slope facies are promising to explore for shale gas. The intra-basinal carbonate banks

facies of the same age are promising for adsorbed (shale) gas in the shale carbonates and unconventional gas in tight carbonate rocks. Shelfal facies zone sequence is prospective for unconventional gas in tight carbonate rocks. The reefal facies zone rocks are non-prospective for unconventional hydrocarbons because these are favorable for conventional reservoirs. The rocks of lagoonal and littoral facies zones are unviable for unconventional hydrocarbons. Top priority exploration activity for unconventional should be targeted to tight carbonate rocks of the shelfal zone. The rocks sequence of the open marine basin, slope as well as intra-basinal facies should be considered a second priority exploration target because of their minor area development (that stipulated by their too deep occurrence in most of cases.

REFERENCES

Lukin A. E., Vakarchuk S. G., 1999. Tournaisian – Lower Visean carbonate reefal complex of the Dnieper-Donets basin and general issues of early Carboniferous reefs formation as hydrocarbon habitats. *Geological Journal*, vol. 2, pp. 21-33. (In Russian).

Лукин А. Е. Турнейско-нижневизейский рифогенно-карбонатный комплекс Днепровско-Донецкой впадины и общие проблемы формирования раннекаменноугольных нефтегазоносных рифов / А. Е. Лукин, С. Г. Вакарчук. // *Геологічний журнал*. – 1999. – №2. – С. 21–33.

Lukin A.E., 2010. Shale gas and perspectives of its development in Ukraine. Paper 1. Shale gas problem status quo. *Geological Journal*, vol. 3, pp. 17-33. (In Russian).

Лукин А. Е. Сланцевый газ и перспективы его добычи в Украине. Статья 1. Современное состояние проблемы сланцевого газа / А. Е. Лукин. // *Геол. журн*. – 2010. – №3. – С. 17–33.

Lukin A.E. 2011. Shale gas perspectives for the Dnieper-Donets aulacogene. *Geological Journal*, vol. 1, pp. 21-41. (In Russian).

Лукин А. Е. Перспективы сланцевой газоносности Днепровско-Донецкого авлакогена / А. Е. Лукин. // *Геол.журн*. – 2011. – №1 – С.21 - 41.

Mykhaylov V.A., Vakarchuk S.G., Zeykan O. Yu., Kasianchuk S.V., Kurovets I.M., Vyzhva S.A., Zagnitko O.Yu., Koval A.M., Krupsky Yu.Z., Gladun V.V., Chepil P.M., Stryzhak V.P., Kultchytska G.O., 2014. Unconeventional hydrocarbon resources in Ukraine. Vol. VIII. Theoretical substantiation of unconventional hyrdocrabon resources in the sedimentary basins in Ukraine. Kyiv, *Nika-Centre Publ*., 280 p. (In Ukrainian)

Нетрадиційні джерела вуглеводнів України. Книга VIII. Теоретичне обґрунтування ресурсів нетрадиційних вуглеводнів осадових басейнів України / [В. А. Михайлов, С. Г. Вакарчук, О. Ю. Зейкан та ін.]. – Київ: *НІКА-ЦЕНТР*, 2014. – 280 с.

Vakarchuk S., Gladun V., Dovzhok T., et. al. 2012 Shale Gas Opportunities in Ukraine: Geological Settings, Reserves Assessment and Exploration Problems. Abs. CD-ROM 34th IGC, Brisbane, Australia, 5-10 August 2012.

Shale Gas Opportunities in Ukraine: Geological Settings, Reserves Assessment and Exploration Problems [Електронний ресурс] / [S. G. Vakarchuk, V. V. Gladun, T. E. Dovzhok та ін.] // Brisbane, Australia, 5-10 August 2012. – 2012. – Режим доступу до ресурсу: Abs. CD-ROM 34th IGC.

Vakarchuk S.G., 2003. Geology, lithology, and facies of the Visean stage carbonate rocks in the central part of Dnieper-Donets basin in relation to their hydrocarbon potential. Chernigiv, *CSTEI*, 163 p. (in Ukrainian).

Вакарчук С. Г. Геологія, літологія і фації карбонатних відкладів візейського ярусу центральної частини Дніпровсько-Донецької западини в зв'язку з нафтогазоносністю / С. Г. Вакарчук. – Чернігів: *ЦНТЕІ*, 2003. – 163 с.

Vakarchuk S.G., Dovzhok T.E., Filyushkin K.K., Kabyshev Yu.B., Gladun V.V., Maksymchuk P.Ya., Kharchenko M.V., Bashkirov G.L., Vertyukh A.M., Danyshurka N.A., Kitchka O.A., Kholodnykh A.B., 2014. Unconventional hydrocarbon resources in Ukraine. Volume VI. Development potential for tight gas rocks in the Eastern petroleum province of Ukraine. Kyiv. *BTC PRINT Ltd*. 208 p. (In Ukrainian).

Нетрадиційні джерела вуглеводнів України. Книга VI. Перспективи освоєння ресурсів газу ущільнених порід у Східному нафтогазоносному регіоні України / [С. Г. Вакарчук, Т. Є. Довжок, К. К. Філюшкін та ін.]. – Київ: *ТОВ «ВТС ПРИНТ»*, 2014. – 208 с.

Vakarchuk S.G., Zeykan O.Yu., Dovzhok T.E., Mykhaylov V.A., Gladun V.V., Shvydkyy O.A., Vyzhva S.A., Filyushkin K.K., Kharchenko M.V., Kabyshev Yu.B., Bashkirov G.L., 2013. Unconventional hydrocarbon resources in Ukraine. Vol. V. Development potential for shale gas and oil resources in the Eastern region of Ukraine. Kyiv. *BTC PRINT Ltd*., 240 p. (In Ukrainian).

Нетрадиційні джерела вуглеводнів України. Книга V. Перспективи освоєння ресурсів сланцевого газу та сланцевої нафти у Східному нафтогазоносному регіоні України / [С. Г. Вакарчук, О. Ю. Зейкан, Т. Є. Довжок та ін.]. – Київ: *ТОВ «ВТС ПРИНТ»*, 2013. – 240 с.

Manuscript resived 21 December 2014;
revision accepted 11 March 2015.

Дочірнє підприємство «Науково-дослідний інститут нафтогазової промисловості» Національної акціонерної компанії «Нафтогаз України»,
Вишневе, Україна
vakarchuk@naukanaftogaz.kiev.ua
Рецензент: О.Ю. Митропольський