Geological features of Ukrainian shale formations promising for the presence of industrial unconventional hydrocarbon accumulations in connection with hydraulic fracturing

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Abstract

Ukraine continues to hype up the unconventional oil and gas issue. The main prospects are associated with unconventional shale reservoirs and tight sandstones, which imply fracturing for subsequent commercial production. According to new data, Ukraine keeps the third position in Europe and the thirteenth in the world in resources of unconventional hydrocarbons. Estimated resources are 128 Tcf (3.6 trillion cubic meters). According to the research of Ukrainian geologists, shared resources of the Western, Eastern and Southern regions may reach 700 trillion cubic feet. The main prospects are in the Eastern oil and gas region (70% of resources) at Carboniferous sediments of Dnieper-Donets Basin, in the Western oil and gas region (17%) they are allocated in shale formations of Volyn-Podolia, in the Southern region (13%) - on Crimea peninsula and Preddobrudzhe foredeep [6]. Two large international companies Shell and Chevron that received wide license blocks, have got permission for exploration and production of unconventional hydrocarbons and have already begun exploratory drilling.

Lithologic and mineral, geochemical and mechanical properties of unconventional reservoirs in Ukrainian oil and gas regions are very diverse due to the extensive lateral and vertical distribution and various genesis. The data which we operate for studying the above mentioned formations were obtained due to geophysical and laboratory studies, which were conducted during drilling of other target horizons. We have developed petrophysical techniques for assessing the prospect of sediments for presence of productive unconventional hydrocarbon accumulations. It is necessary to supplement these methods with mathematical mechanism to assess the success of fracturing in promising deposits, based on available data. In the coming years, the results of the exploration works will give impetus for wide drilling campaigns, followed by hydraulic fracturing, which causes increased attention to this issue.

As far as Dnieper-Donets basin is the main hydrocarbon production region of Ukraine and contains 70 percent of unproved unconventional hydrocarbon resources, it is in the limelight of all those involved in the unconventional oil and gas industry including hydraulic fracturing industry that we decided to focus on.

1 Unconventional prospects at Dnieper-Donets basin

The Dnieper-Donets basin (DDb) is a rift graben that is 70-130 km wide and more than 800 km long in the northwest-southeast direction in the southern Ukraine and partly in Russian Federation and Belarussia (Figure1). The sedimentary cover of DDb is 10-12 km thick and consists of four tectono-stratigraphic sequences - Late Devonian rift, which is overlain by a Carboniferous to Early Permian postrift sag and younger postrift platform. Discovered conventional reserves of the petroleum system are 1.6 billion barrels of oil and 59 trillion

cubic feet of gas (86% is gas) [5]. Half of the HC are in Lower Permian sandstone reservoirs below the salt formations, second part of HC is in Lower Carboniferous deeper sediments. Well-recognized source-rock object is Rudov beds consisting of black anoxic shales (total organic carbon content is 3-12%) between the Lower and Upper Visean, but according to the common point of view, most of Lower Carboniferous and Devonian argillaceous sediments are source rocks but organic-lean. All those sequences are interbedded with sandstones (figure 2) that makes promising intervals heterogeneous and excludes the possibility of effective fracturing. We've been comparing genesis of black organic rich shales and noted that absolute majority of shale gas formations in North America are overlying or underlying carbonate platforms. By the way, this specialty applies only to Rudov beds in DDb.

However, there are additional unexplored organic-rich horizons in the depressions - the central parts of the DDb (figure 1 and 2) that pushes it to a spotlight among exploration geologists. According to results of several scientific investigations - shales and sandstones of DDb at depth that exceeds 5500-6500 meters are characterized by very unusual mineralogical composition with unpredictable mechanical and petrophysical properties and it will become an objective of future works. It's worth mentioning as sandstone core samples from depth 6200-6400 meters had unrealistic porosity over 12%, that was explained by washed out carbonate cement by deep thermal waters. This process affected sandstone structure which entails very important changes that can become significant while modeling and implementing hydraulic fracturing in deep tight reservoirs.

The above mentioned black shales are in the gas-generation window (vitrinite reflectance is above 0,9%) over most area of the basin. Those mentioned source rocks are the main prospects for shale gas exploration in DDb and they are available for future drilling only along the regional faults because of large depth exceeding 7-9 km and more. The same situation can be observed in connection with tight gas deposits and central basin gas accumulations.

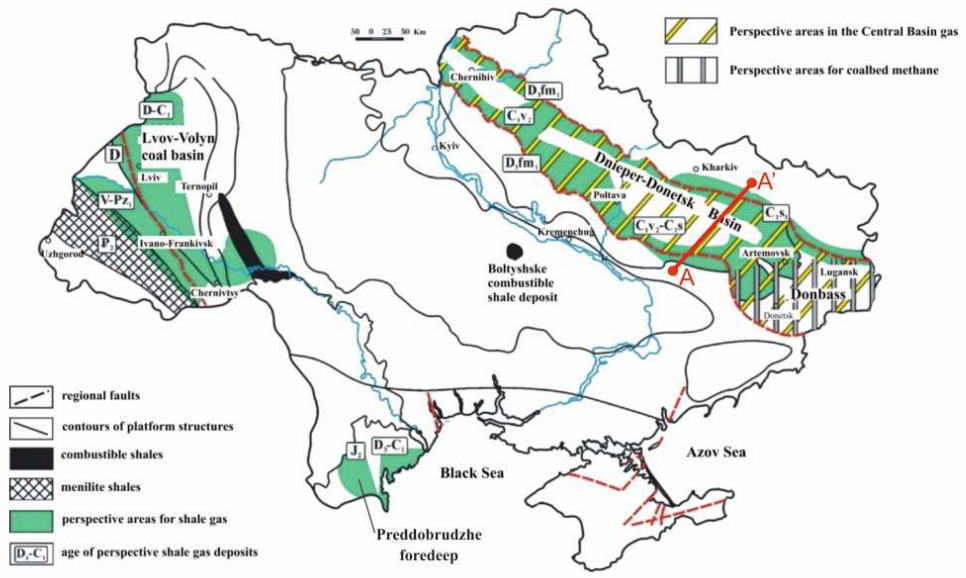

Figure 1: Schematic map of Ukraine with prospective zones for unconventional hydrocarbons; red line AA'- cross section represented on Figure 2 (by Lukin A.E.)

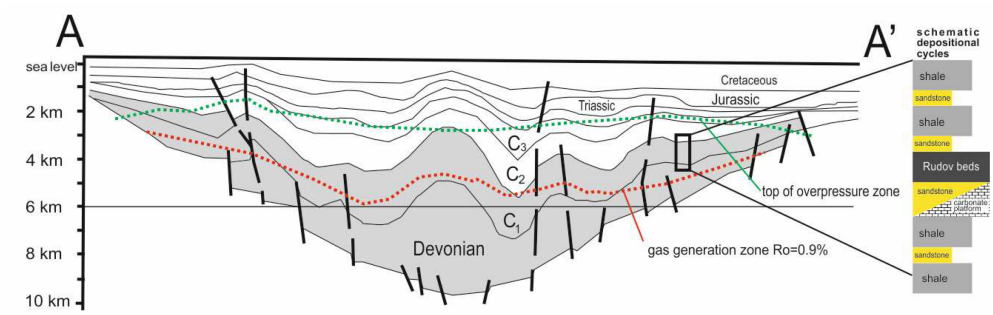

Figure 2: Schematic cross section of Dnieper-Donets basin along the line AA'; shaded zone - prospect of unconventional shale hydrocarbons; C_{1-3} - Carboniferous; on the right - schematic image of depositional cycles.

2 Petrophysical basics for diagnostics of unconventional shale reservoirs and its prospects

Petrophysical model of unconventional shale reservoir is more complex than conventional reservoirs in connection with more variable components' content and additional components such as kerogen, pyrite, adsorbed gas, nanoporosity etc. (Figure 3). The comparison of clay/carbonate/quarts ratios strongly differs in unconventional shale plays and can be variable along the single play. Main components are combination of clay minerals and matrix which is represented by carbonate or clastic minerals. Matrix volume to clay minerals volume ratio strongly affects the rock brittleness. Increased content of kerogen, its maturity stage and its geochemical parameters are primary indicators of potential hydrocarbon content. Primary (interparticle) porosity in unconventional shale reservoir is usually saturated with bound water, bound hydrocarbons, water with dissolved hydrocarbons, or mostly hydrocarbons and doesn't usually exceed more than few percent. Secondary (interparticle) porosity, formed during katagenesis inside micro particles of kerogen, is mostly isolated from other pores and differs from the classical porosity of conventional reservoirs by pore size measured in nanometers. By the way, intraparticle pore volume of kerogen can reach half of its volume. Most organic rich shales, especially oil prone, include bitumen that is very similar to hydrocarbons and kerogen in reflection to geophysical fields and prevent accurate petrophysical evaluation. Evaluation of total and effective porosity volume, hydrocarbon and water saturation, matrix volume and shale volume is the classical petrophysical problem which can be solved during interpretation of well-logging data. But this is solution only for a half of the problem because we need to identify brittleness of prospect formations.

All petrophysical methods for volumetric content determination of all reservoir components are based on component's properties which differ much. Therefore, the physical fields are different and logging tools record this. Kerogen, bitumen and hydrocarbon parameters are similar and differ from other components' parameters that contain them. On the basis of these distinctions we make diagnostics, assessment and calculation.

As already mentioned, monomineralic composition is not typical for unconventional shale formations and can be characterized by various compositions (Figure 2). The data on the triangle chart shows that content of quartz and feldspar can wary between 20-80 percent, the amount of clay minerals content wary: 10-80%, and carbonate minerals: 15-90%. Increasing of clay minerals content decreases rock brittleness, and 50% of clay content

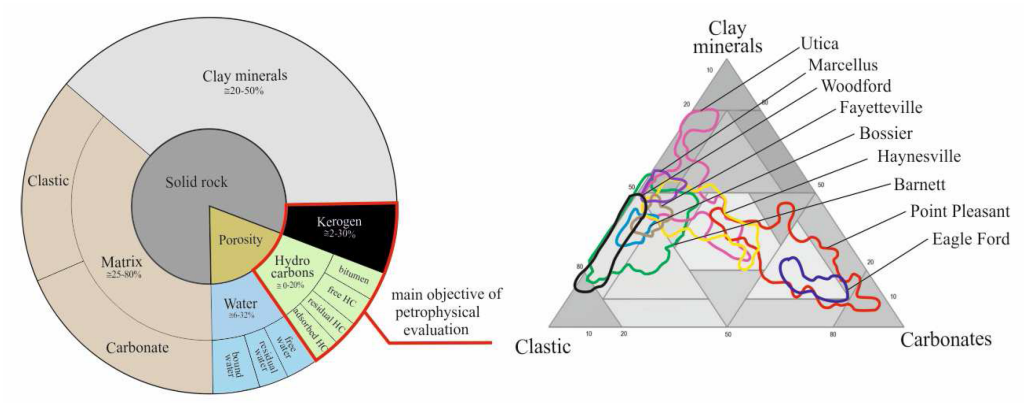

Figure 3: Componential petrophysical model of unconventional shale reservoir (on the left) and various compositions of North American hydrocarbon producing shale plays (on the right).

is a critical value [2].

3 Petrophysical determination of rock brittleness as the second half of the success

The second most important parameter of unconventional shale reservoirs is brittleness. It depends on matrix components, its orientation and structure, clay minerals composition and its ratio to matrix components and on kerogen content. There are certain well known techniques to determine rock brittleness using logging data by Jarvie et al. (2003), Breyer et al. (2011), Rickman et al. (2008) [1]. Determination of Brittleness Index requires Poisson's Ratio and Young Modulus as well as volumetric and mineral compositions that can be calculated from shear velocity and compression velocity (Vp and Vs) or one of those values in combination with density and sonic logs [2]. As far as modern geochemical logging data provides mineralogical and volumetric characterization, the same bulk mineralogy can be determined by calculating conventional well logs using the system of linear equations. There are various charts for different lithological compositions to determine parameters that affect brittleness. Facies analysis is a usual petrophysical technique in geomodeling of conventional and unconventional reservoirs. The well known method is to use only two main parameters for geomodeling of unconventional reservoirs - Brittleness Index and TOC content (or HC saturation), which provides understanding of most promising objects during exploration stage. But Brittleness Index is not a perfect and sufficient indicator of fracability, that's why we need a new method, especially in case of exploration for unconventional accumulations, in basins where exploration for conventional hydrocarbons continues for a long time and there is a lot of data available from the abandoned wells. We have already started to work on this methodology with our new colleagues from Aberystwyth University.

Our colleagues from V.N. Karazin Kharkiv National University have published results of their studies about mathematical modeling of hydraulic fracturing using liquefied propane [4]. This technology is geologically and environmentally efficient as compared with well-known hydraulic fracturing since disclosure of rocks using natural hydrocarbon components contained in industrial fields. It is known that the viscosity of fluid is the measure of

resistance to flow and it is inversely proportional to its fluidity. The viscosity of liquefied propane as against water is 8 times smaller, which allows it to leave artificial thinning area eight times easier. According to the author's calculations, this technology increases production in 1.5-2 times in comparison with well-known hydraulic fracturing with water use.

We have come to the obvious conclusion that all the issues related to exploration and subsequent production of unconventional shale hydrocarbon resources in Ukraine require careful and painstaking research work and highly qualified management. Such studies should embrace the whole range of issues -, geological, economic, technological, environmental, social and political, but such studies in Ukraine are hardly carried, except for only few isolated exceptions. For the last three years a team of experts from Kyiv National Taras Shevchenko University, Subsidiary Enterprise "Scientific-research institute of oil and gas industry", National Joint Stock Company "Naftogaz of Ukraine", Institute of Geology and Geochemistry of Combustible Minerals of Ukraine, the Expert Council of the Union of Geologists Ukraine, State Enterprise "Zahidukrheolohiya", Western Ukrainian geophysical exploration expedition, Ivano-Frankivsk National Technical University of Oil and Gas and others have gathered significant new facts on the sedimentary basins of Ukraine in connection with unconventional hydrocarbon resources. But of course, this is only a very small part of the necessary information. Therefore, to continue further research it is recommended to conduct comprehensive research of potentially hydrocarbons-bearing shale formations of Ukrainian sedimentary basins and the implementation of geological and economic studies to justify the development of shale gas on the basis of environmental risks.

Acknowledgements

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