THE PROSPECTS OF OIL AND GAS CONTENT OF THE SINIAN SYSTEM OF THE SICHUAN BASIN OF CHINA

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Problem statement. The role of energy innovations is crucial in the development of the world energy sector. Incredible success of the USA in the production of unconventional shale gas led to considerable revaluation of the hydrocarbon resources in the world. This success became possible thanks to two production technologies which had been developed and introduced by that time — formation hydraulic fracturing and lateral drilling. Since 2005 gas production in the United States has increased by 18% mainly thanks to shale gas. This phenomenon allowed speaking about the so-called “shale revolution” and aroused wide interest connected with a possibility of the production of shale gas in other counties. In the long-term prospect, unconventional gas sources promise quite substantial gain for countries which have strict dependence on the import of natural gas (China, EU countries, Ukraine, the USA and others). If only 10 years ago the share of unconventional gas in the structure of natural gas reserves amounted to less than 5%, today the value of the world reserves and resources of unconventional gas exceeds the value of the reserves and resources of conventional natural gas practically by five times.

The biggest reserves of shale gas belong to China (36 trillion cubic metres), the USA (24 trillion cubic metres) and Argentina (21 trillion cubic metres). The fourth place is occupied by Mexico (19.2 trillion cubic metres). At present active exploration of gas fields are being carried out in Canada, Europe (Poland, Denmark, Sweden, Ukraine and the United Kingdom), Australia, Israel and in other countries.

Great quantity of shale, rich in organic substances, which is promising for geological prospecting work as potential projects sites for shale gas production was found in China. With the estimated geological reserves of gas of 144.4 trillion cub. m (5,101 trillion cub. feet), of which 36.1 trillion cub. m (1,275 trillion cub. feet) is considered to be techn-
nically recoverable, this potential is compared to the resource potential of North America. China plans to produce 6.5 billion cub. m of gas by the end of 2015, 50 billion by 2020, 80 billion by 2030 and 164 billion by 2040.

The purpose of the article is the analysis of the prospects of oil and gas content of the Sichuan system of the Sichuan Basin of China.

The analysis of previous researches. The question of the prospects of oil and gas content of China was studied at different times by such scientists as Chzhan Khoufu, Tsziin Chzhitsyun, Bi Yanpen, Chen Yulin, Tyan Bo, Van Tsze, Guan Defan, Gun Tszaisen, Dai Tszinsin, Kuskhina K.S., Li Syaodi, Chzhan Guanya, Tyan Tsotszi, Lyu Khefu, Sun Tsyachzhen, Khu Guantsan, Su Zhaosyan, Khu Tsyan, Syui Shubao and Chzhao Venchzhi.

The statement of the main material. Two large sedimentary basins in China – the Sichuan Basin in the south and the Tarim Basin in the west are of particular interest. These two basins which include thick mass of shale rich in organic substances cover vast areas and have good reservoir properties for development. Let’s consider the prospects of oil and gas content of the Sinian system of the Sichuan Basin in greater detail.

The Sichuan Basin is a formed basin, developing on the cratonic foundation of the Yangtze, its area amounts to approximately 18 x 10^5 km². The sedimentary beds of the basin have formed completely and their thickness amounts to 6,000-12,000 m. The upper Sinian section – the medium Triassic section is represented by sea deposits; carbonate rock with the thickness of approximately 5,000 m is considered to be its foundation. The Sinian system includes horizons Doushantu and Denying the thickness of which amounts to 300-1,200 m. The horizon Denying is represented by algal and crystalline dolomites and the horizon Doushantu is formed of deposits of arenaceous argillites. In 1964 the most ancient gas field Weiyouan was found on the paleolegde of Leshan-Lunnyuisy of the Sichuan Basin; the horizon Denying of the Sinian system with developed geological reserves of 400 x 10^8 m³ is its producing layer. The paleolegde Leshan-Lunnyuisy is a large paleolegde of the Caledonian period with the area of 6 x 10^8 m². After finding the gas field Weiyouan, in 70-90-ies of the 20th century a part of the core and a high-wail area were found near the paleolegde Leshan-Lunnyuisy after which a number of prospecting operations were carried out on the producing horizons of the Sinian system. As a result, 11 structures such as Lunnyuisy, Anpingdian, Ziyang and some other structures were drilled and 16 wells such as Khenyuitszi, Anping, Tszy and some other wells of which 4 wells are economic gas wells, 4 wells are gas wells with poor efficiency, 1 well is a non-productive well, 7 wells are water wells were drilled. Including, besides the test volume of daily gas production of 1.85 x 10^4 m³ at a depth of 5,206-5,248 m of the Sinian system in the well Nyuitszin which was drilled as far back as in 1971, in 1993-1997 an economic gas stream with the daily production volume of (5.33-11.54) x 10^7 m³ was received in the well Tszy 1, the well Tszy 3 and the well Tszy 7 which were drilled in the ancient trap Ziyang. The received test and forecast geological reserves of natural gas amounted to 102 x 10^9 m³ and 338 x 10^8 m³ respectively.

In recent years, a system analysis of the facies deposits of the Sinian system, the oil-source rock and the analysis of the conditions of oil and gas accumulation were carried out. Thanks to this, 4 auspicious exploratory prospective areas, including the area of the paleolegde Leshan-Lunnyuisy, were chosen in an optimal way.

3 large paleolegdes are being developed in the Sichuan Basin: the paleolegde Leshan-Lunnyuisy of the Caledonian period, the paleolegde Luzhou of the Indo-Chinese period and the paleolegde Kaijiang of the Indo-Chinese period. These 3 paleolegdes are of great importance for oil and gas accumulation and the accumulation of oil and gas in the Sichuan Basin.

1. The structure of reservoirs and cap rock as the basis for large-scale development of the oil-source rock

The horizon Doushantu and the horizon Denying are being developed in the Sinian system of the Sichuan Basin. The horizon Doushantu is formed of sandstone with interlayers of argillites and dolomites the thickness of which amounts to 90-460 m. This horizon can be found in the central part and on the periphery of the basin. The horizon Denying is represented by algal dolomites, crystalline dolomites, sandy dolomites, with interlayers of sand, argillites and silicates. The thickness of this horizon in the central part of the basin amounts to 500-1,200 m. Based on the contents of the algae, it is possible to divide the horizon Denying into 4 lithological sections from the bottom upwards: the section Den 1 is formed of light grey – dark grey crystalline fine-dispersed dolomites. This horizon is called “the lower section poor in algae”. The section Den 2 is represented by light grey, dark grey algal dolomites, with interlayers of crystalline dolomites and clayish and crystalline dolomites and is called “the lower section rich in algae”. The section Den 3 is formed of dark grey – grey fine-crystalline bedded dolomites and is called “the upper section poor in algae”; in the lower part of this section clay shale is developed. The section Den 4 consists of light grey – dark grey crystalline dolomites, containing arenari-
ous fragments and algal dolomites. This section is called “the upper section rich in algae”.

The Sichuan Basin is part of the cratonic basin Upper Yangtze. The movement of Chengjiang before the sediments of the Sinian system produced a great influence on the paleogeographic conditions of the sediments of the Sinian system. The movement of Chengjiang is a classical epeirogenic movement which is deemed to be caused by the elevation of the continental crust as a result of which a distinct erosion boundary surface was formed, suggesting that in the initial period the elevated paleocontinent was exposed to deposit accumulation; afterwards the paleocontinent started descending, becoming an epicontinental sea. On this paleogeographic background the shelf coastal depositional system of the deposition period of the horizon Doushantuo of the Sinian system and the flat-lying restricted platform depositional system of the deposition period of the horizon Denying were formed.

For the early period of the deposition of sediments of the horizon Doushantuo the foundation consists of the accumulation of shelf sediments, mainly, the sediments of argillites, clayish dolomites and sandy dolomitic sediments. Black argillites of the shelf facies of the horizon Doushantuo are relatively thick on the periphery of the basin, the maximum thickness can amount to 150 m, the thickness in the central part of the basin is relatively small and usually amounts to 0-80 m. The thickness of black and greyish-green shale of the horizon Doushantuo in the southern areas of Eastern Sichuan is relatively big; the thickness of argillites of the section Zunyi Sungling amounts to 75 m; these are relatively thick beds of clay oil-source rock which can be found in a large area. For the late period the foundation of the deposition of sediments consists of coastal deposits which are represented by the deposition of arenaceous argillites. The horizon of Doushantuo of the central part of the basin is characterized by clastic coastal sediments and in the eastern part shelf facies are being developed and high quality oil-source rock of the horizon Doushantuo is being formed.

For the period of the deposition of sediments of the horizon Denying the foundation consists of local platform sediments. Sunpan in Western Sichuan which is part of the basin is a paleocontinent. In the central part of the basin large-scale platform sediments represented by dolomites are being developed; the sediments of vaporable lacustrine facies are being developed fragmentarily. The horizon Denying in the central part of the basin is on the whole the environment for platform deposition of carbonate rock; intraplatform shoals, dolomitic plateaus, sand clastic banks and other subfacies are being developed; subfacies of internal banks and subfacies of dolomitic plateaus serve as favourable phase belts of reservoirs and cap rock.

Based on the data of 25 exploratory wells of the Sinian system which were drilled in the whole basin, the key exploratory wells of the structure Weiyuan and the data connected with the outcrop of the bedding rock of the periphery of the basin, based on the study of the facies sediments, a diagram of facies sediments of the section Den 2 was formed. Since in the central part of the basin there are very few wells which are drilled till the section Den 1 and the horizon Doushantuo, there is no planar diagram here. In 90% of areas in the central part of the basin mainly limited platform facies represented by subfacies of internal platform banks and subfacies of dolomitic plateaus are developed. On the eastern edge of the basin small facies with a smooth slope are being developed; arenaceous clastic bank subfacies are being developed in internal parts of small facies with smooth slopes. During the period of the deposition of sediments in the section Den 4 there was deepening with water masses, the palaeogeographical boundaries of the petrographical facies were moving eastwards and small smooth slopes eastwards were stepping back from the Sichuan Basin. The whole basin is characterized by limited petrographical facies.

Subfacies of a dolomitic plateau of the limited platform facies and bank subfacies inside the platform are a favourable phase belt of reservoirs and cap rock, there is development in the section Den 2, the section Den 3 and the Section Den 4; bank subfacies inside the platform and subfacies of the dolomitic plateau (Picture 5) are mainly being developed on the plane within the boundaries of the whole basin; the conditions for large-scale development of deposits are ensured.

2. Promising exploratory areas

2.1. The promising exploratory areas of the paleoledge Leshan-Lunnyuisy

These areas are situated within the province of the core and the slope area of the paleoledge Leshan-Lunnyuisy. The favourable exploratory area amounts to approximately 4×10⁴ km² where the gas field Weiyuan, the gas-containing structures Ziyang and Gaoshiti-Mosi the proved geological reserves of which amount to 400×10³ m³ were found. There is development of karst deposits in the section Den 2, the section Den 3 and the section Den 4 which during the movement of Tunyan were exposed to elevation and washout; the processes of resorption and washout are being developed. The horizon Denying of the area Ziyang is characterized by the development of karst and the ancient crust of weathering. The crust of weathering of the hanging layer of the Sinian system is regional deposits. In the areas Ziyang and Weiyuan the confirmation of drill holes which are high rate gas-containing wells was carried
out. According to the data of the well logging and the core samples collection, the horizon Denying has the characteristics of the ancient crust of weathering.

Proceeding from the analysis of the conditions of the accumulation of the paleoledge Leshan-Lunnyuisy one can make a conclusion that this paleoledge is a favourable promising exploratory area of the Sinian system of the Sichuan Basin. This exploratory area can be divided into 3 types:

The first type includes the most favourable promising areas which are long-term hereditary palaeostructures. The structure Gaoshiti-Mosi-Lunnyuisy is the most exemplary. This structure was on a structural upland for a long time, permanently being an oriented area of the migration of oil and gas; in addition, it has a large area of structural traps, a big resource potential, being the best area for carrying out exploratory operations. In the southwest areas of Sichuan within the province of the core of the paleoledge similar structures which must serve as promising areas for subsequent surveys can be developed.

The second type includes relatively favourable promising areas which are slope areas between the structure Weiyuan and the structure Gaoshiti-Mosi. This area during the period of the accumulation of oil and gas was constantly near the core of the paleoledge. In the Himalayan period due to an elevation of the structure Weiyuan it became a slope area. On this territory anticline and lithological traps which can serve as promising areas for subsequent surveys are being developed.

The third type includes the periphery of the area of the core of the paleoledge which has a wide range of distribution; the conditions of accumulation are similar to the conditions of the core here. For a long time this area was on the way of the migration of oil and gas; its certain structures, belts of lithological plugging and belts of wedging-out of beds are the best for exploration in this area.

2.2. The promising exploratory areas of the South-West of the Sichuan Basin

These areas are situated in the south-east part of the Sichuan Basin and their area amounts to 5 × 10^4 km². The paleoledge Luzhou which was formed in the Indio-Chinese period of the development is similar to the paleoledge Leshan-Lunnyuisy and is a hereditary paleoledge. A lot of structural traps of the Sinian period with a large area are being developed inside the areas; the storage of the traps is integral. According to some statistical data, in these areas in the Sinian system 40 traps with an area which exceeds 10 km² are being developed, the total area amounts to 4,200 km²; there are 27 traps the area of which exceeds 20 km², the total area amounts to 4,000 km². The degree of the exploration of these areas is small, there are only 5 wells which were drilled till the Sinian system.

It is taken into account that the conditions of accumulation, facies sediments and deposits of the Sinian system of this area are similar to the paleoledge Leshan-Lunnyuisy. It is situated in the centre of the generation of hydrocarbons of the oil-source rock of the horizon Tsyunchzhus of the Cambrian system, the intensity of gas generation is (50-120)×10^8 m³/km², the distance from the centre of the generation of hydrocarbons of the oil-source rock of the horizon Doushantuo of the Sinian system is closer. The distinctive features as compared to the paleoledge Leshan-Lunnyuisy are relatively developed fragmentation, non-integrity of structural traps in the Sinian system.

2.3. The promising exploratory areas of the Eastern part of the Sichuan Basin

The area which can be explored in promising exploratory areas of Eastern Sichuan amounts to 2×10^5 km². At present there are no wells which are drilled till the Sinian system; in addition, these areas are areas of the development of the structure Gaodou of Eastern Sichuan with respect to which there are seismic data of bad quality that’s why the degree of the interpretation and understanding of the characteristics of the distribution of beds of the Sinian system is very low. Proceeding from the characteristics of the sediments of the Sinian system in the rock exposure on the eastern edge of the Sichuan Basin and the assumptions about the ancient geomorphology of the sediments of the Sinian system of the basin, a favourable structure of reservoirs and cap rock of subfacies of the dolomitic plateau of the restricted platform and arenarious clastic bank subfacies of small smooth slopes is being developed here. In particular, there are relatively good physical properties of the deposits of arenarious clastic bank subfacies, the average porosity amounts approximately to 3.5%. Besides, there is a big potential of the generation of hydrocarbons of two beds with sources of hydrocarbons: of the horizon Tsyunchzhus of the Cambrian system of the development and of the horizon Doushantuo of the Sinian system, the intensity of gas generation amounts to (40-100)×10^8 m³/km². These are the promising exploratory areas of the Sinian system of the Sichuan Basin.

2.4. The promising exploratory areas of the North-West part of the Sichuan Basin

The area which can be explored in promising exploratory areas of North-West Sichuan amounts approximately to 1×104² m². At present in these areas there are no wells which are drilled till the Sinian system, beyond the boundaries of the basin there are 4 wells for drilling. The structure in these areas is complex, the quality of seismic data is bad,
the degree of the understanding of the characteristics of the distribution of the beds of the Sinian system and facies sediments is very low. In the horizon Tsunyichzhus of the Cambrian system there are a lot of kerogenic sheet deposits, which explains rich oil and gas resources of the deposits of the Sinian system and a relatively high exploration potential.

**Conclusions.** The Sinian system of the Sichuan Basin has the main basic conditions for the formation of large gas fields. A large hereditary paleoledge ensures the formation and accumulation of oil and gas of the Sinian system. Persistent sediments in the area laid a foundation for large-scale development of the structure of reservoirs and cap rock and also the oil-source rock. In this basin there is mutual over-placement of 3 deposits in the section Den 2, the section Den 3 and the section Den 4 with large-scale distribution. Great quantity of oil-source rock is bedded in the vertical direction and can be found in a large area, creating the structure of alternation of beds like “a sandwich” with the deposits. The regional argilous cap rock is thick, the fragmentation inside the basin is not being developed, the storage conditions are favourable. All this determines a great exploration potential of the Sinian system.

In accordance with the differences in the conditions of accumulation in different regions, 4 promising exploratory areas of the Sinian system were chosen in an optimal way: the promising exploratory areas of the paleoledge Leshan-Lunyuysi, the promising exploratory area of South-East Sichuan, the promising exploratory areas of Eastern Sichuan and the promising exploratory areas of North-West Sichuan. The ancient structural traps of the area of the core and the slope parts of the paleoledge Leshan-Lunyuysi are also the most promising areas for the exploration of bedded and lithological gas deposits.

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ГЕОХІМІЧНІ КРИТЕРІЇ ПОШУКІВ ВУГЛЕВОДНІВ НА СХОДІ ДНІПРОВСЬКО-ДОНЕЦЬКОЇ ЗАПАДИНИ

Розглянуті геохімічні критерії пошуків вуглеводнів на сході Дніпровсько-Донецької западини. Виявлено закономірності формування геохімічних аномалій над скопленими вуглеводнів. Встановлено просторово-часові взаємовідносини між процесами гідротермального мінералоутворення та нафтогазонакоплення в антиклінальних структурах, що є важливою ознакою при прогнозуванні покладів нафти і газу.

У процесі геохімічних пошуків вуглеводнів на сході ДДЗ застосовувалися переважно газогеохімічні, гідрогеохімічні і меншою мірою – літогеохімічні (битумінологічні), а також біогеохімічні методи. З’ясовано, що одним із показників нафтогазонакоплення є специфічна схема формування газогеохімічної та гідрогеохімічної зональності, а також гіпсометричне положення верхньої межі «метанової зони». Встановлено, що одним з найважливіших пошукових критеріїв нафтогазонакоплення є просторово-часові співвідношення утворення скоплень вуглеводнів та гідротермалітів у верхніх частин хвильових форм. У випадку, якщо гідротермальна мінералізація у породах певної геологічної структури є молодшою за процеси нафтогазонакоплення, газогеохімічні аномалії над скопленнями вуглеводнів було виявлено при прогнозуванні покладів нафти і газу.

В.Г. Суярко, Л.В. Іщенко. ГЕОХИМИЧЕСКИЕ КРИТЕРИИ ПОИСКОВ УГЛЕВОДОРОДОВ НА ВОСТОКЕ ДНЯПРОВСКО-ДОНЕЦКОЙ ВПАДИНЫ. Рассмотрены геохимические критерии поисков углеводородов на востоке Днепровско-Донецкой впадины. Выявлены закономерности формирования геохимических аномалий над скоплениями углеводородов. Установлены пространственно-временные взаимоотношения между процессами гидротермального минералообразования и нафтогазоналожения в антиклинальных структурах, что является важным признаком прогнозирования залежей нефти и газа. В процессе геохимических поисков углеводородов на востоке ДДВ использовались преимущественно газогеохимический, гидрогеохимический и в меньшей степени – литогеохимический (битуминологический), а также биогеохимический методы. Выяснено, что одним из показателей нефтегазоносности являются специфические схемы формирования газогеохимической и гидрогеохимической зональности, а также гипсометрическое положение верхней границы «метановой зоны». Установлено, что одним из важнейших поисковых критериев нефтегазоносности являются пространственно-временные соотношения образования скоплений углеводородов и гидротермалитов. В случае если гидротермальная минерализация в породах определенной геологической структуры является более молодой, чем процесс нафтогазоналожения, поиск месторождений углеводородов в ее непосредственно практическом неперспективен.

Ключевые слова: углеводороды, геохимические методы, гидротермальная минерализация, нефтегазоносность, Днепровско-Донецкая впадина.