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Shale Gas: Ecology, Politics, Economy

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Shale Gas: Ecology, Politics, Economy

Volume Editor: Sergey S. Zhiltsov

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geoecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry,* there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry,* the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

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Introduction

Sergey S. Zhiltsov

Abstract The idea of shale gas production has appeared nearly two centuries ago. But only in the recent decades, the technologies of the shale gas extraction were developed which permit the commercial scale of shale gas production; thus, it became possible to speak about the "shale revolution." The pioneer in this field was the USA which achieved considerable success here. At the same time, other countries that launched the shale gas production project have not been as successful as the USA so far. Regardless of this fact, the shale gas production affected significantly the arrangement of forces in the global gas market forcing many countries to take into consideration this factor in evolving their energy strategies.

Keywords Ecology, Hydrocarbon resources, Production, Shale gas

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1 Introduction

The history of the shale gas production dates back to the early nineteenth century when the first wells were drilled which demonstrated the possibility to extract gas from shale plays. However, that time the applied technologies were not sophisticated enough to ensure shale gas production in commercial scale [1].

Natural shale gas refers to unconventional hydrocarbons, and it is a variety of natural gas, one of the kinds of the so-called unconventional natural gas. This is a commercial term meaning natural gas trapped in clay shales, coalbed methane, and tight gas in dense sandstones, occurring at great depths under not high pressure in geological zones.

Shale gas is the hydrocarbons contained in shales being the parent rocks. Shales represent the sedimentary rocks with a high content of organic matter that is required for formation of oil and gas and mostly consists of methane. Apart from methane, the shale gas contains ethane, propane, butane, and non-hydrocarbon compounds. The specific feature of such gas plays is that hydrocarbons in them occur in very dense, nearly impermeable rocks.

High temperatures and high pressure are conducive to formation of new minerals. The organic matter turns into oil and gas. The shales are distinguished by low porosity and low permeability. Gas in shale rocks spreads evenly through the whole formation. The amount of the extracted gas depends on the thickness of formation and its density. The thickness of formations in some areas may be as large as 100 m. The depth of occurrence of formations varies widely: from several 100 m to several kilometers. The formation pressure in gas parent rocks may be often abnormally high. The formation temperatures depending on the depth of occurrence may range from 80 to 180°C. This requires specific technologies for gas recovery.

In the second half of the nineteenth century, the new technological solutions appeared that permitted to extract considerable volumes of shale gas. This stirred greater interest to the shale gas having made the search for new solutions of this gas production more energetic. In the USSR, the technologies of the shale gas production have been developed since the 1950s and in the USA since the 1970s.

These researches were conducted largely as experiments because the availability of immense natural gas resources made unattractive the development of shale plays. Nevertheless, the Soviet scientists paid much attention to the theoretical aspects of the shale gas production. The theory of the shale gas production was developed by Academician S. A. Khristianovich at the Institute of Oil of the USSR Academy of Sciences. That time it was proposed to pump pressurized fluid into a well; as a result, the formation was fractured. This technique referred mostly to the increase of oil production and was targeted to attaining the greater oil yield of formations.

Greater interest to the technology of shale gas production was shown in the USA. Unlike the USSR where shale play development was of experimental nature, the USA got down energetically to development of the technologies capable to increase the gas recovery from shale rocks. Quite revolutionary was application of hydraulic fracturing in the Klepper play in Kansas. This method for experimental purposes was first applied in 1947 by Stanolind Oil and Gas Corporation (at present Amoco Corporation) and in 1949 by Company Halliburton. The fracking technology was tested in Oklahoma and Texas.

The hydraulic fracturing is applied to create the "web" of fractures by pumping quickly large amounts of fresh water and sand as proppant into rocks. This technique requires specific technological equipment permitting to create pressure above 100 MPa and to pump water at a rate more than 15 cu. m/min. This technology proved to be effective, and during several decades, the great number of hydraulic fracturing was done in the USA.

The solutions used in hydraulic fracturing (fracking) are usually water based. The additives ensure transportation of the proppant with water to the fractures. Water accounts for over 98% of the applied solution, and the rest fraction is various additive chemicals.

Beginning from the 1980s, the shale gas in the USA was treated as an alternative to the traditionally produced natural gas.

The insistent efforts in the USA to develop the shale gas production technology were successful – from the 2000s the USA initiated the commercial scale extraction of this gas having become the leader in production of this hydrocarbon resource.

At the turn of 2008–2009 when the USA due to application of new technologies achieved a quick surge in its production outrunning Russia in this field, the interest to the shale gas has enormously grown in different countries. The volume of the shale gas production was estimated in dozen billion cubic meters which was comparable to the volumes of production and consumption in some countries. This stirred animated discussions concerning the perspectives of this hydrocarbon resource. The politicians and experts in many countries started speaking about the end of the epoch of the traditional natural gas.

Many experts agree that gas recovery from shale rocks has led to breakthrough in technologies. The construction of single wells was substituted by horizontal drilling from one well into which the working solution is pumped. Breaking of walls of gas pockets by fracking allows for significant increase of the gas recovery that is pumped out via the vertical borehole. This technology makes unnecessary the construction of on-field gas pipelines and the drilling process proper becomes more accurate [2].

The USA success in shale gas production gave an impulse to extensive research to evaluate the shale gas reserves. In view of certain difficulties with evaluation of reserves, the obtained data may be treated only as rough estimates giving only preliminary information about the reserves of this hydrocarbon resource.

The more extensive researches revealed many cases of gas play occurrence and spreading in complicated, unusual, in other words, nontraditional conditions. By the end of the twentieth century, the hydrocarbon resources of some unconventional accumulations (gas hydrate, heavy oil, shale oil, methane hydrate, gas of dense reservoirs), including shale gas, exceeded much the resources of their traditional analogs, while the beginning of the twenty-first century was marked by transition to their wider application in many world countries.

The geological reserves are estimated at trillion cubic meters and represent the world's "reserve fund" of hydrocarbons. Regardless of the absence of accurate data about the shale gas reserves and availability of only tentative figures based on expert assessments, the published data on prospective reserves are quite impressive. In 2010 the US Department of Energy started calling the gas from unconventional sources as gas from low permeability reservoirs.

The new technologies of shale gas production, such as horizontal drilling of "intellectual" wells applying the innovative technique of seismic modeling 3D GEO, as well as technologies of multiple fracking have transformed the gas sector. New technologies have drawn greater attention to the shale gas of major petroleum and gas companies and different states that started viewing this gas as a new means to ensure their energy independence and industrial base development.

As a result, the shale gas changes very quickly the energy landscape of the gas market. And although many forecasts concerning the reserves and production level of this gas have not come true, still the factor of shale gas has produced a significant impact on the energy policy of many world countries. It is not accidental that in many countries the shale gas is considered as a resource and geopolitical factor. Initiation of the commercial scale production of shale gas has become the key factor that affected strongly the world gas market in the recent decades.

If further development of technologies ensures lowering of the costs of commercial production of shale gas, it is quite likely that already by 2020–2025 the North American shale gas might appear in the world market. At least, the permanent reduction of costs of shale gas production allows for such forecasts.

The shale gas production has become recently one of the key issues not only in the world energy, but in the world politics, too. The experience of the USA in this business that has boosted up rapidly the shale gas production seems rather tempting. Many countries have seen their opportunities to develop production of their own shale gas expecting in the future to alleviate their dependence or even to refuse completely from hydrocarbon import.

The "shale revolution" – the term actively used in mass media and in the popular science literature played its role in formation of the energy map of the world. First of all, the success in shale gas production has influenced the US energy policy – the import of natural gas was cut drastically, and the options of their own gas export to foreign markets were considered. So far the shale gas depends on the oil prices which drop in 2014 urged the oil and gas companies engaged in shale gas production to adjust their activities. Notwithstanding this, the USA remains the leader in shale gas production. In 2010–2014 the gas sale price in the USA has dropped from 210 to 70 dollars per 1,000 cu. m. Many American companies conduct operations on shale gas extraction at a loss keeping the license in the sole hope for growing prices in the future [3].

The growing production of shale gas in the USA has led to considerable increase of gas prices in the American market and abandoning one of the Russia's largest projects – development of the Shtokman gas field in the Barents Sea which reserves are estimated at 3.9 tcm of gas and 56.1 million tons of gas condensate.

At the same time, it should be noted that the first attempts of the “shale revolution” export ended in a failure. The experience of the USA that managed to improve its energy security due to development of shale gas plays has been of limited application elsewhere.

Taking into consideration the depletion of the traditional gas resources, the shale gas cannot as yet become the reliable alternative to the natural gas in the near future [4].

But nevertheless it should be said that the interest to development of the shale gas fields remains high, and, first of all, in the USA. It is not accidental that some researchers believe that by the mid-2020s the shale gas will account for nearly the half of the US gas balance [5].

In the recent years, numerous fundamental works investigating various aspects of shale gas prospecting, production, and transit have appeared.

Regardless of non-optimistic attitude to the future of shale gas, we, Russian Company Gazprom, considered all complicated issues related to its production. This problem was studied in the books *Shale Gas* [6] and *Shale Flash Mob: Technologies, Ecology, Politics* [7].

Springer Publishers have turned to this problem more than once. It is sufficient to name such publications as “Sedimentology of Shale. Study Guide and Reference Source” [8], “Economics of Unconventional Shale Gas Development (Case Studies and Impacts)” [9], “Integrative Understanding of Shale Gas Reservoirs” [10], and “The Global Impact of Unconventional Shale Gas Development. Economics, Policy and Interdependence” [11].

The leaders of many countries are directly involved in addressing the issues of hydrocarbon production and transit, including gas, focusing much attention on this problem.

The European countries keep the shale gas production in the focus of attention as they endeavor to diversify the hydrocarbon supply sources, including by development of own shale gas plays. And among the first who not only showed the scientific interest to the shale gas production but made the first steps in this direction were Britain, France, and Poland. But as soon as they started extraction of shale gas, they faced some problems. Apart from the lack of reliable data about the shale gas reserves (Fig. 1), these countries faced the powerful public movements against the techniques applied in shale gas production. Accordingly, these countries had to make adjustments in their plans and adopt tougher requirements to producing companies.

Following the European countries, some post-Soviet states also made attempts to organize development of this hydrocarbon resource. The most energetic here was Ukraine that started inviting foreign petroleum and gas companies to such business. Meanwhile, the shale gas production was manipulated for attaining some political goals, and this made difficult the assessment of the starter conditions and likely consequences for the public and natural environment that appear in the course of shale gas production.

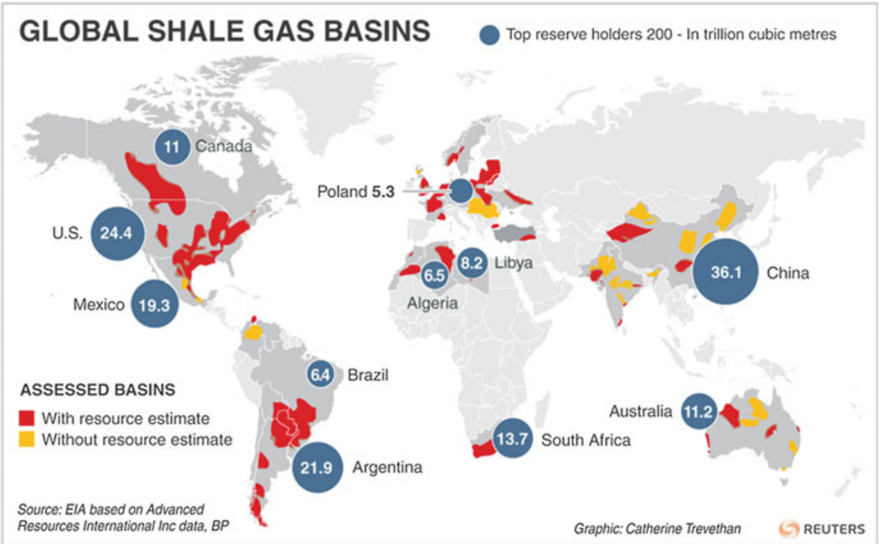

Fig. 1 Global shale gas basins and resources (trillion m^3) (http://www.energy-without-carbon.org/sites/default/files/Shale-gas%20reserves.jpg)

Shale gas was in the focus of attention of the leadership in Kazakhstan and Moldova which started considering this hydrocarbon resource as a significant factor in implementation of the policy of hydrocarbon source diversification.

This "shale rush" appeared as a result of the coordinated information activities of US companies producing shale gas and state structures supporting them. Promoting the idea of energy independence, the USA was ready to get rid of the old equipment and technology and, at the same time, to obtain the multibillion orders for its petroleum companies operating in this business. Thus, still prior to launching the prospective drilling, the numerous speculations were circulating about enormous shale gas reserves in many world countries capable to ensure their energy independence. As a result, many countries not waiting even for rough estimates of the shale gas reserves rushed for their energy independence.

The "shale revolution" was not missed in Russia being one of the major suppliers of natural gas to the European market. In Russia the researches related to shale gas production have been conducted since the 1950s. Later on the shale gas was extracted in the USSR, but in insignificant quantities and, largely, for research purposes. Extraction of gas from shale plays was not vital for Russia in view of its enormous natural gas reserves, including in the Arctic seas. However, in the recent years, Russia had to take into consideration the shale factor in the global energy adjusting its price policy.

In 2014–2015, the experts and politicians continued their discussions concerning perspectives of development of the global gas market with regard to the shale gas factor (Fig. 2). This was facilitated by appearance of new technologies opening access to the previously inaccessible fields and also construction of terminals for

Fig. 2 "Time" about future of shale gas (http://shalegas-europe.eu/wp-content/uploads/2014/02/TIME.jpg)

re-gasification of liquefied natural gas (LNG) and availability of the tanker fleet capable to bring it to different world regions.

The world financial crisis and growing hydrocarbon prices (till 2014) spurred the commercial development of unconventional oil and gas. In 2010 the world production of shale gas amounted to 137 bcm. In the recent decade, the extraction of this hydrocarbon has increased 14-fold which, of course, has produced its psychological effect on the main players of the global hydrocarbon market. According to IEA, by 2035 the fraction of unconventional gas in the world production will reach 20% and of oil – around 10%.

The “shale revolution” stirred lively discussions of the environmental consequences of activities of the petroleum and gas companies. The reason for the ecology to be in the focus of attention was connected, primarily, with the negative environmental consequences of shale gas production. The hydraulic fracturing technology is detrimental for the natural environment causing irreparable damage to nature [12]. Ii should be added here that shale gas production requires enormous volumes of water and application of a wide range of chemicals.

In conclusion it should be stressed that shale gas influenced greatly the political and economic development of many countries, facilitated development of new technologies and affected the world gas market.

With further progress of technologies permitting to update the previous forecasts, the shale gas production has been given a new impulse. Many countries started treating the shale gas fields as the basis for their energy policy.

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Shale Gas: History of Development

Sergey S. Zhiltsov and A.V. Semenov

Abstract The history of shale gas production goes back more than two centuries. The production of this hydrocarbon resource was pioneered by the USA that accumulated considerable experience in development of the shale gas plays. The shale gas play development pushed further the development of new technologies that ensured considerable increase of this hydrocarbon resource production, thus, affecting the situation in the global gas market.

Keywords History, Production technology, Shale gas

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1 Introduction

The first information about the shale hydrocarbon production appeared in the nineteenth century. However, in that time, the cost of shale gas development was very costly, so the commercial production of this gas was not attained. Regardless of this fact, the production technologies were permanently improved. The pioneer here was the USA that for many decades made their best to advance the production technology.

A real breakthrough in the shale gas production was attained with the appearance of the hydraulic fracturing technology that permitted to increase enormously the volumes of shale gas extraction. Combined with application of chemicals and directional drilling, this technology provided for considerable increase of shale gas extraction within a short time.

In the recent decades, many petroleum and gas companies turned their views to the shale gas production. The development of shale plays became a part of the state policy in many world countries. Their efforts to develop shale gas plays were supported by the endeavors to attain energy independence.

2 Shale Gas: Definition

Shale gas is a kind of natural gas trapped within shale formations representing the sedimentary rocks containing a great quantity of organic matter required for petroleum and gas formation and consisting mostly of methane (Fig. 1). Apart from methane, the shale gas also contains ethane, propane, butane, and some non-hydrocarbon compounds.

The natural gas fields are usually confined to sandy soils, while shales are denser soils – clay stones with low porosity composed of smaller and more solid particles.

Fig. 1 An organic-rich fine-grained sedimentary rock called shale (http://www.thomaswhite.com/wp-content/uploads/2012/08/img-shale-gas-the-fuel-for-future.jpg)

The shales proper are the type of sedimentary rocks most widespread on the Earth. They are parent rocks of hydrocarbons migrating further into permeable reservoir formations forming traps for petroleum and gas in the underlying sedimentary rocks.

In the conditions of high temperature and high pressure, the new minerals are formed. Here the organic material turns into petroleum and gas. The shales are distinguished by low porosity and low permeability. Here gas spreads evenly through the whole shale play. The quantity of extracted gas depends on the thickness and density of a shale play where organic and mineral material prevails. The play thickness varies from one meter to some hundreds of meters with the depth of occurrence from several hundred meters to several kilometers.

Shale gas is one of the so-called unconventional forms of natural gas. The *unconventional gas* is an industrial term denoting natural gas trapped in clay shales, in coalbeds, and in dense sandstones occurring deeply in the geozones under not high pressure.

3 History of Shale Gas Production

The USA is justly considered the parent land of the "shale revolution." The first commercial gas well was drilled in the shales in 1821 in America by William Hart who is considered in the USA the "father of natural gas." The gas producing well was drilled in shale formations in the state of New York.

In the 1920s US engineers Floyd Farris and J.B. Clark suggested the hydraulic fracturing technology that became the platform for further researches and permitted to get down to practical production of shale gas. The USA initiated shale gas field development in the states of Kentucky, Michigan, Ohio, and Indiana. By the end of the last century, they were the main sources of shale gas production. The development of these fields was facilitated by such factors as shallow shale occurrence and their development by vertical wells. The average production was about 5–6 billion cubic meters per year [1].

In the 1950s, the former USSR also developed technologies of shale gas production, but these researches were conducted largely for experimental purposes. The theoretical basis of the technology for shale gas extraction from rocks was developed by Soviet Academician S. A. Khristianovich at the Institute for Oil Research of the USSR Academy of Sciences. This technology implied injection into a well of liquid under pressure that would break geological formations. This method permitted to increase oil recovery from formations.

Unlike the USSR where the shale gas plays were developed on a limited scale, the USA showed great interest to extraction of this hydrocarbon resource. Stanolind Oil and Gas Corporation (presently Amoco Corporation) in 1947 conducted trial hydraulic fracturing in the Klepper play in the state of Kansas. That time the experiment was considered unsuccessful as there was not increase of gas production [2]. However, already in 1949 Company Halliburton used the hydraulic fracturing technology in the states of Oklahoma and Texas applying water and sand as propping reagents. This technology proved effective, and in the next decade, a great number of fracking operations were conducted in the USA.

The successful application of the hydraulic fracturing technology spurred the researches in this field targeted to increase the efficiency of shale gas extraction in the developed plays. In 1976 the Energy Research Center in Morgantown, USA, launched the “Eastern Project” connected with the shale gas research. The goal of this project was to study the possibilities of gas extraction from shales and other unconventional sources in order to make the country less dependent on oil supplies. The US Department of Energy financed into development of the shale gas production technologies. In 1977 with the ministry’s support, the mass hydraulic fracturing of shale play for gas recovery was conducted in the state of Colorado, USA (Fig. 2).

The first experimental developments of gas extraction from shale plays were initiated in 1980 in the USA by Mitchell Energy and Development headed by George P. Mitchell, one of the US Top 200 richest businessmen. Specializing in petroleum engineering, he started his career in the Oil Drilling Company and later on became its shareholder. Some time passed and George P. Mitchell and his brother bought out the remaining shares and renamed the company into Mitchell Energy & Development.

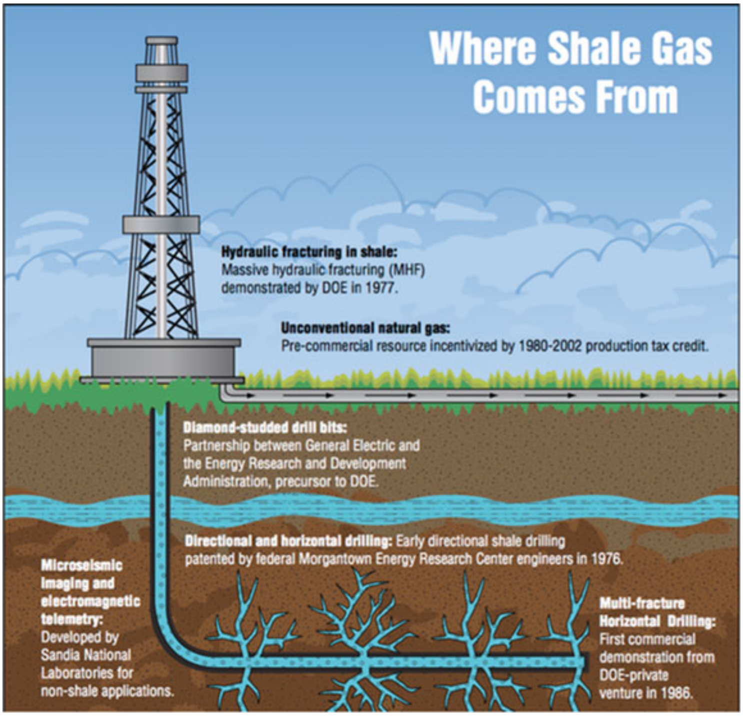

Fig. 2 Where shale gas comes from (http://thebreakthrough.org/blog/Shale_Gas_Infographic-thumb-550x529.png)

In the early 1980s, the company possessed the Barnett play in the Northern Texas that was considered to have poor prospects. Many wells were drilled, but with no success and with several million dollars of investments for 10 years. However, that time the shale gas plays were inaccessible, and development of the respective technologies of shale gas production was stopped after the oil price drop in the 1980s. But the company did not completely abandon its endeavor to develop shale plays. This was facilitated immensely by the fact that beginning from 1980 the companies engaged in development of unconventional energy sources were granted the tax credit in accordance with the US federal law.

The financial crisis triggered the mass application of new technologies. Among the stakeholders were such widely renowned multinational corporations as BP, Royal Dutch Shell, Total, and Statoil. However, the leader of the “shale rush” was Chesapeake Energy of Oklahoma that owned the shares of Barnett, Fayetteville, Bossier, Haynesville, and also Marcellus Shales. Apart from Chesapeake, the leading gas producing companies in the USA specializing in shale gas production are such companies as Apache, Devon Energy, and Noble Energy.

In 1997 Mitchell Energy & Development applied the hydraulic fracking technology with the use of propping reagents which gave positive effect. After this the company was quickly developing bringing dividends to its owners.

The Barnett Shales of Texas where George P. Mitchell tried to attain the commercial scale of shale gas production was the testing ground for the directional drilling technology. It is from this very play that the shale gas epoch started. Tom L. Ward and his company Chesapeake Energy were also working in this direction from 1989.

4 Technology of Shale Gas Production

The shale gas production has its specific features. Shale gas is recovered from hard rocks which drilling involves many difficulties. In addition, the gas reserves in such formations are much smaller than in traditional gas fields.

The shale plays are distinguished, first, by confinement to hard rocks which drilling is difficult; second, small resources, i.e., small quantity of gas per unit of play; and, third, low permeability of shale formations so the gas flows by microfissures to the borehole at a low rate.

In view of high density and strength of the shales, the only technique to recover gas from them is destruction of the formation with hydraulic fracturing (HF) when the hard rocks are broken with water and specific chemical reagents.

The hydraulic fracturing (HF) is the use of fluid and material to create or restore small fractures in a formation in order to stimulate inflow of the target fluid (gas, water, condensate, oil, or their mix) to the borehole. The HF technology includes pumping into a well of specialty fluid and after this adding of the propping agent with the help of powerful pumping plants for fracturing fluid (consisting of chemicals, sand, water, and acids that corrode the walls of fractures in a formation) under a pressure higher than the pressure for fracturing the oil and gas formation. For hydraulic fracking, the pressure varies from 500 to 1,500 atm. This creates numerous fractures in a formation housing shale gas. The natural sand or other artificial material pumped together with water serve to keep fractures from closing up. After this the water is pumped out and sand fills the expanded fractures and let gas flow freely to a well along which it moves up to the surface. In this way the highly conductive fracture is formed in a hard rock that ensures considerable growth of well yield. The released gas moves up along the wellbore. Regarding the depth of occurrence of a formation, the vertical wells to 2 km deep and more are drilled. Moreover, the companies have already learned how to construct horizontal branches 1.5–2 km long.

As a result of hydraulic fracturing, the walls separating gas “pockets” are broken, and the released gas is pumped out through the vertical wellbore [3]. The directional drilling is also used for shale gas extraction which improves significantly the efficiency of shale gas production.

The determining factors of the reservoir productivity are the type of rocks and threshold systems. Permeability, thickness, pressure of a formation, and viscosity of a formation fluid are the components of the main equation of productivity.

The thickness of formations containing shale gas is averaging from several meters to dozens of meters. Accordingly, the standard vertical drilling provides the insignificant quantity of gas.

For increase of the gas extraction from formation, the directional drilling technique was developed which permits to drill a horizontal well going along a formation and inside it. The technique of 3D maps made on the basis of microseismic data is applied for accurate determination of well coordinates. The wellbore deviation is controlled by an operator locating on the surface. The length of a horizontal well averages several kilometers.

The directional drilling was developed more than 70 years ago and became a breakthrough that allowed for increase of the shale gas production. But initially this technique was not widely applied due to its high cost, and only in 1986, the multiple hydraulic fracturing of formation was successful. In the 1990s, the expenses on directional drilling became less due to the reduced costs of materials and drill pipes, but still the cost of a horizontal well was nearly fourfold higher than that of traditional vertical well.

The drainage area of a well is very small and the quantity of gas extracted by one well is also not large. The caloric power of shale gas is twice lower than of natural gas. In addition, it contains carbon dioxide, nitrogen, and hydrogen sulfur; thus, the shale gas in the USA is used only as fuel for domestic needs in settlements located not far from its production points from where it may be transported via low-pressure gas lines.

To ensure stable shale gas production, it is necessary, first, to drill new and new wells which cost is evaluated in the USA as 2.6–4 billion dollars; second, to have vacant land sites for well construction; and, third, to have a great number of drilling rigs and pumping plants for multiple hydraulic fracturing of formations. Usually one hydraulic fracturing operation requires about 4,000 tons of water and 200 tons of sand. During a year from 3 to 10, HF may be performed with each well. Accordingly, every year 7.1 million tons of sand and 47.2 million tons of water are needed for hydraulic fracturing. The average daily yield of a well is around 6,000 cubic meters, i.e., about 50% of wells are performing periodically or idling.

With low concentration of shale gas in a play, the drilled wells quickly decline their production – by 30–40% per year. In 3 years of operation, the shale well gives only 14% of its initial production. For this reason, the service life of shale wells varies from several months to 5 years (the wells constructed for natural gas production perform for 50 years). Moreover, the unconventional hydrocarbon resources require specific production techniques that increase significantly the costs of their development.

This explains the fact that only around 2.5 million hydraulic fracturing operations have been made in the world, out of which about 1 million in the USA. Without hydraulic fracturing, the commercial scale of shale hydrocarbons is impossible [4].

In the recent years, the shale gas production technology includes drilling of a vertical well and several horizontal wells with multiple branches at the same depth. The construction of multistep horizontal wells with the horizontal wellbore length to 3 km is currently practiced. A mix of water, sand, and chemicals is pumped into drilled wells. The hydraulic fracturing breaks the walls of gas reservoirs, thus, allowing for extraction of all accessible gas. At directional drilling, the seismic modeling 3D GEO is applied combining geological surveys and mapping with computerized data processing, including visualization.

In the recent years, the cluster drilling technology is applied when several horizontal wellbores are drilled from the vertical well. This improves significantly the efficiency of shale gas production.

5 Conclusion

In the 1990s, some small US companies returned to the idea of gas recovery from shales. This was facilitated by development of new technologies applying directional drilling and performance of certain works in a well for hydraulic fracturing of formations using great volumes of water and surfactants. At the same time, gas consumption in the USA has boosted quickly due to wide construction across the country of efficient and environmentally friendly combined cycle power units, while the gas prices were rather high.

The technology of shale gas production that was developed some decades before was offered: inside a formation, the drill rig was gradually deviated from the vertical until it reached the angle of 90°, and then the rig continued moving parallel to the ground surface (horizontal drilling). This technology was applied for the first time in the 1940s, but it was abandoned in view of high costs.

In the gas-bearing shales, the mix of water, sand, and special chemicals was pumped into such horizontal wells. It was assumed that the hydraulic fracturing would break the walls of gas pockets and permit accumulation of all gas resources making drilling of numerous low-value vertical wells unnecessary. The developments of the 1990s and application of new materials for drill pipes reduced considerably the costs. But regardless of this fact, the cost of horizontal well construction for shale gas production remained still higher than that of the traditional vertical well – nearly four times, on the average.

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The Evaluation of the World Potential of Shale Gas Reserves

Sergey S. Zhiltsov and Igor S. Zonn

Abstract At present there are no accurate estimates of the shale gas reserves in the world as we have no so far reliable techniques to determine the size of shales entrapping shale gas. In the recent decades, some additional geological surveys were conducted which provided new data about shale gas reserves in different world regions. However, all available forecasts may be treated as tentative as they give only potential volumes of shale gas that could be extracted by applying available technologies.

Keywords Global gas market, Reserves, Shale gas

Contents

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1 Introduction

There are no accurate data about the shale gas reserves in the world and we have so far only rough global estimates. One of the reasons for the absence of accurate data about shale gas reserves is that prior to 2011 the shale gas production was conducted only in North America [1] and nowhere else.

In the recent years, some changes are visible. Surveys of shale gas reserves were initiated in different countries. As a result, new verified data about reserves of this hydrocarbon resource worldwide and in different regions and countries started appearing. Such attention to the shale gas reserves in some countries may be connected with potential of its production which is considered a new path to attaining energy independence.

Such information is greatly needed by the oil and gas companies that are ready to risk and invest their money into development of shale gas plays. While in the USA the shale plays are developed both by large oil and gas companies and small companies ready any time to change their market strategy, then in Europe the world's leading oil and gas companies having experience in development of similar plays are attracted to survey and production of shale gas (Fig. 1).

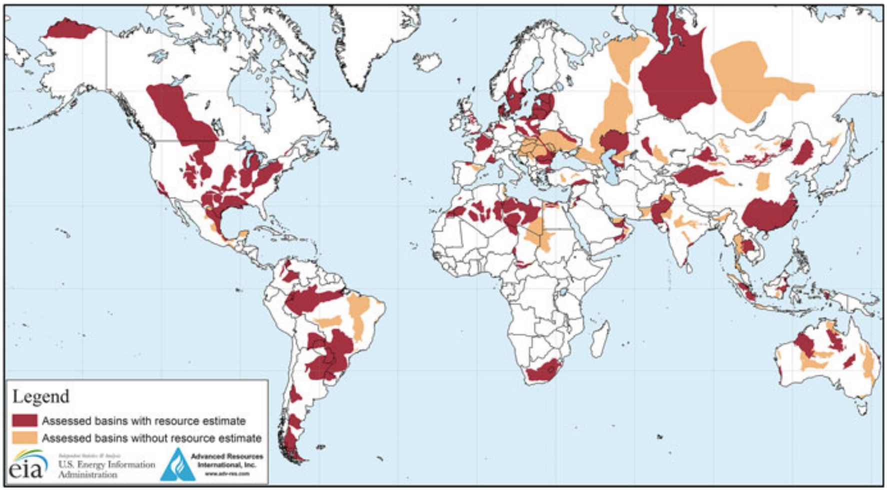

Fig. 1 Shale gas assessed basins in the world (https://www.eia.gov/analysis/studies/worldshalegas/images/EIA_ARI_World_Shale_Gas_Oil_Basins_Logos_Map_092215_HighRes.jpg)

2 Preliminary Estimates

For over 15 years, all sources citing data about considerable shale gas resources were based on the publication of German specialist in energy economics Hans-Holger Rogner written still in 1997. The German expert estimated the global shale gas resources at 456 tcm referring at the same time to his figures as "speculative."

For many years the data published by Hans-Holger Rogner were not used. However, after sharp boost of the shale gas production in the USA, the interest to the German expert's data has grown. They are used by the International Energy Agency (IEA) as well as by sectoral experts and representatives of companies. As a result, the data on the shale gas resources are abundant, but their reliability is very low; accordingly, the data on the global reserves of shale gas may be considered only tentative. They depend greatly on the techniques applied for evaluation of shale plays.

There are also expert estimates made by representatives of various international organizations and research companies. Thus, IEA evaluates the global shale gas reserves at 200 tcm, while the International Atomic Energy Agency (IAEA) estimates the world gas reserves in shales at nearly 500 tcm. More than one decade will be required to survey these resources, and the final results will be, most likely, adjusted significantly.

In general, the data for the same shale plays in different reports vary greatly. The reason for this should be sought in preliminary, often tentative, evaluations of shale gas reserves that can be confirmed or disproved only by exploratory drilling.

Shale gas is found on all continents, and their considerable reserves are available in more than 40 countries (Fig. 2).

3 Geography of Shale Reserves

The shales from which gas can be extracted are great and may be found on all continents possessing considerable areas of sedimentary rocks. However, the shale gas reserves are distributed very unevenly and the data on them are rather contradictory. The shale gas reserves are estimated at 200–450 tcm, and these data are constantly changing due to the lack of scientifically reliable data about the nature of shale gas, regularities of shale play formation, the criteria of their forecast, survey, and prospecting [2].

The proven gas reserves in the world are 182 tcm, of which, according to IEA, the unconventional reserves account only for 4% or some 7 tcm of gas [3]. Nevertheless, the statistics agency at the US Department of Energy in March 2011 increased the reserve level having assessed the world recoverable gas reserves (conventional and unconventional) to 640 tcm, of which 40% or 256 tcm account for shale gas. Here only high-quality formations promising in terms of shale gas production were considered.

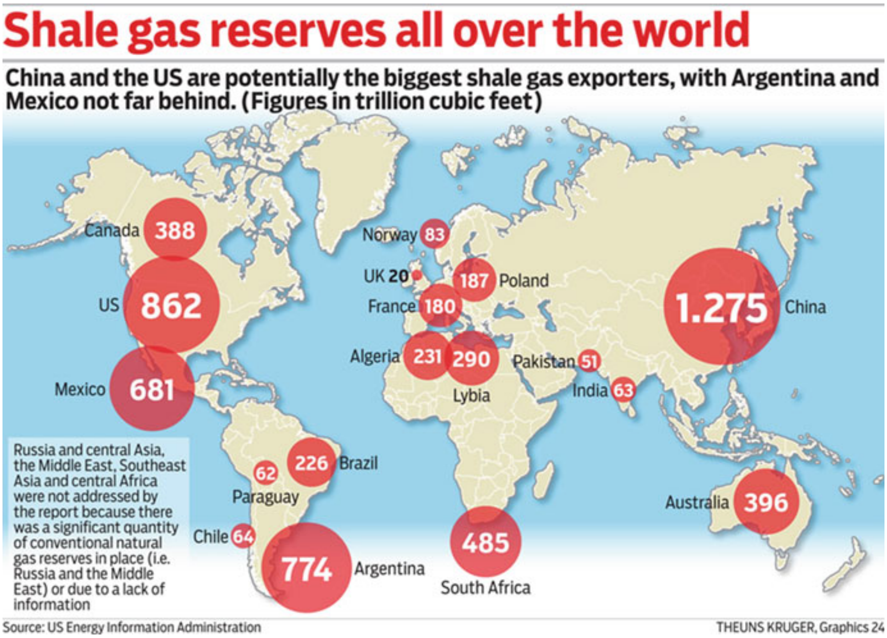

Fig. 2 Shale gas reserves in the world (http://www.grafika24.com/wp-content/uploads/2012/09/Shale-gas-reserves-all-over-the-world-WP.jpg)

In 2011 the US Energy Information Department published its report "World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States" where it was stated that the technically recoverable shale gas resources in the world were estimated at 185 tcm. This report analyzed 48 shale gas plays in 32 world countries. According to the authors, the USA accounted for 13% of the world resources and China for 19%, while the shale gas resources of Europe were assessed at 10% of the world reserves.

The proven resources of shale gas in the USA are estimated at 24 tcm, of which the recoverable are only 3.6 tcm. However, in the recent years, the assessments of the shale gas resources were revised and the obtained figures were lower – 14 tcm.

Unlike the USA where the shale gas survey and prospecting have long history, in other world countries, the assessments are only rough. The greatest resources of shale gas are found in China, the USA, and Argentina with Mexico taking the fourth place.

In Asian countries the shale gas reserves amount to 57 tcm. Thus, in particular, China, according to rough estimates, has 45 tcm. But regardless of adoption of the state program that includes the conduct of geological surveys, the shale gas production goes on at a slower pace.

Significant shale gas resources are found in the countries of Latin America, Libya, Australia, Canada, Argentina, and Mexico [4]. The shale gas resources in

Argentina are assessed at 27 tcm. The first well was drilled in 2011, but for the lack of technologies and finance, the shale gas production has not attained wide development.

In the South African Republic (SAR), the shale gas resources are roughly estimated at 17 tcm. But the water deficit, the ban of application of hydraulic fracturing technology, and the lack of foreign investments make the perspectives of shale development rather vague.

Enormous shale gas resources are found in the European countries. The cumulative shale gas reserves here are evaluated at 18 tcm, of which France and Poland account for more than 10 tcm – 5.1 tcm and 5.6 tcm, respectively. Austria, Germany, Britain, Poland, and Sweden also possess perspective resources. The world resources of recoverable shale gas are presented in Table 1 below. The regions and individual countries possessing the largest shale gas reserves are presented in Fig. 3.

Currently the active shale play surveys are conducted in Canada, Europe (Poland, Denmark, Sweden, Ukraine, Great Britain), Australia, Israel, and other countries [5].

Considerable shale gas resources are also found in the post-Soviet countries and, first of all, in Russia, Ukraine, Kazakhstan, and Belarus. Ukraine was the first to start exploration of shale gas plays and verification of available resources (see chapter by Tsivatyi in this book).

In 2013–2015 the data about the shale gas resources in different world regions and in individual countries were updated. In general, many results of new researches coincide with the previously published figures as many data about shale gas resources are taken by researchers from the already published reports without making any adjustments there. As a result, estimates of many resources may be treated as only tentative, probabilistic. Similar situation is observed in many countries, except the USA, where the researches have been conducted for a long time, including by exploratory drilling.

So far the shale gas remains the strictly regional factor influencing significantly only the market of North America, primarily, the USA. In other world regions, there is no shale gas production on a commercial scale, although its resources are available in many countries.

The published data about the shale gas reserves and production has already changed the landscape of the global gas market. Although many of them have not been confirmed so far, but the shale gas factor has already affected significantly the energy policy of many world countries. In the final run, the progressing changes in the global energy market after the "shale revolution" may lead to new structural changes [6].

Table 1 World resources of recoverable shale gas (by countries)

Region/country	Proven natural gas resources, bcm	Recoverable shale gas resources, bcm
Europe		
France	5.6	3,056
Germany	175.5	226
The Netherland	1,386	481
Norway	2,037	2,348
Great Britain	254.7	566
Denmark	59.4	651
Sweden	–	1,160
Poland	164.1	5,292
Turkey	5.66	425
Ukraine	1103.7	1,188
Lithuania	–	113
Others	76.6	537
North America		
USA	7,712	24,395
Canada	1,755	10,980
Mexico	339	19,272
Asia		
China	3,028	36,082
India	1,072	1,782
Pakistan	840.5	1443
Australia	3,313	11,206
Africa		
SAR	–	13,725
Libya	1,548	8,207
Tunisia	65	509
Algeria	4,500	6,537
Morocco	2.8	311
Others	2.8	198
South America		
Venezuela	5,062	311
Colombia	56.6	537
Argentina	379.2	21,904
Brazil	365	6,395
Chile	2,801	1,811
Uruguay	–	595
Paraguay	–	1,754
Bolivia	750	1,358
Total	36,054	187,402

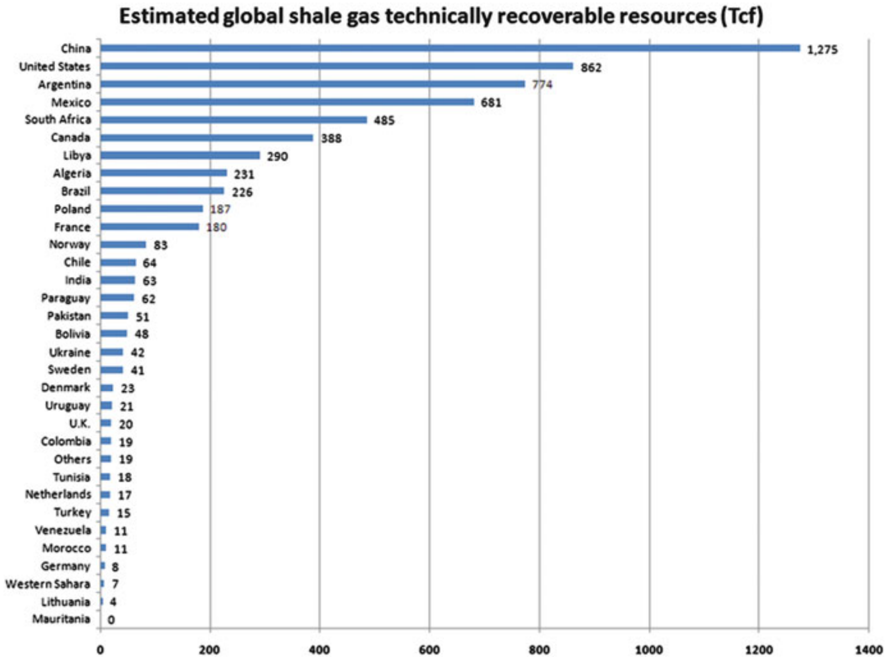

Fig. 3 Estimated global shale gas recoverable resources (http://3.bp.blogspot.com/-vBaFLDhKINA/TZ0bdlzQZZI/AAAAAAAAHG4/JRTIpiIv5-Y/s1600/worldnatgas.png)

4 Conclusions

The soaring growth of the shale gas production in the USA became possible due to long-time investigation of this hydrocarbon resources and drilling in the plays having potential reserves. The attempts of other countries to repeat the US experience were not successful which may be attributed largely to the lack of accurate data about the shale gas resources.

The recently published data about shale gas resources in the world and by regions are only tentative and not confirmed by fundamental research. Accordingly, numerous publications describe only potential possibilities preventing individual countries and oil and gas companies to work up the long-term strategy of shale gas play development. Moreover, in addressing the issues related to the shale gas play development, the political factors often come to the fore, leaving the economic estimates in the background. Thus, using such unverified data, many countries, especially those that depend greatly on hydrocarbons import, are seeking to use the “shale revolution” factor in their foreign policy.

Regardless of only rough assessments of the shale gas resources, this factor has already influenced the formation of the regional gas markets and spurred the negotiations between producers and consumers of gas concerning the price of this hydrocarbon resource. The attempts of some countries to organize the shale gas production draw more attention to further researches endeavoring to obtain more accurate data about this hydrocarbon reserves and also initiating forecasts concerning the future effect of shale gas on the world energy. According to forecasts of the International Energy Agency, by 2035 the shale gas fraction may account for 25–27% and after 2050 reach 40%. But, of course, this forecast will be adjusted by taking into consideration various factors. Shale gas is a local resource, while the reserves of natural gas are great and technologies of their production are developed much better [7].

The estimates of shale gas resources have been changing from time to time as in many world regions the geological surveys are either in their initial stage or they verify the previous estimates. For this reason all published data are mostly positive [8].

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Shale Gas Production in the USA

Sergey S. Zhiltsov and Igor S. Zonn

Abstract The interest to assessing the shale gas resources in the USA has increased at the turn of the twentieth to twenty-first centuries. The success of the US oil and gas companies in commercial scale production spurred the efforts on verification of the data about the available shale gas resources. The shale gas production has created a surge in development of production base and evolvement of new technologies, making the USA the leader in the gas industry. With considerable shale gas reserves, the USA may claim to secure the leading positions and to influence significantly the formation of the world gas market.

Keywords Production, Reserves, Shale gas, Technologies, The USA

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Contents

1 Introduction

The USA possesses considerable shale gas resources, the interest to which has grown since the 1970s. However, regardless of a rather long history of shale gas production, there are only rough estimates of the shale gas resources [1–3].

The Department of Energy contributed much to surveying the shale gas plays in the USA. In the 1970s–1980s, DOE invested around US$ 100 million into prospecting and development of shale gas plays. The money were used mostly for development of the horizontal drilling technology, improvement of the drilling technique, application of multistage fracking technology and water-based reagents, and development of the techniques to draw up 3D maps on the basis of microseismic data (Fig. 1) [4]. The greater interest to development of technologies and investigation of plays was rewarded later on when the horizontal drilling technologies that had been developed earlier were applied in practical work.

The governmental policy in taxation also played its role. It granted privileges to the companies engaged in unconventional gas production. The respective act was passed in 1980 which opened way for small oil and gas companies that initiated surveys of plays and search of means to improve shale gas production. As a result of persistent efforts, in 1999 the Barnett play, Texas, that for 18 years had been the testing ground for production technique perfection yielded the first commercial shale gas flow. Therefore, nearly two decades were required to develop the effective technology of horizontal drilling with hydraulic fracking.

2 Preparation for the “Shale Revolution”

The “shale revolution” was preceded by substantial and long efforts to study shale plays and to conduct exploratory drilling that should have provide data on the shale gas reserves available in the country. Moreover, the gas recovery from unconventional sources, such as shales, was closely connected with the US energy policy. For several decades the USA developed its policy with regard to its long-time interests and

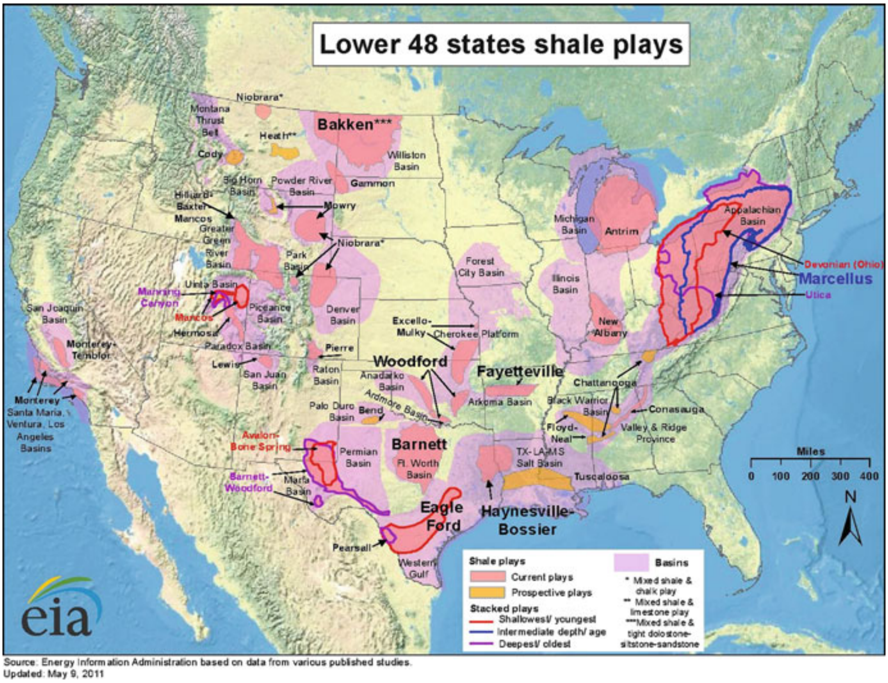

Fig. 1 Shale gas in the USA (https://upload.wikimedia.org/wikipedia/commons/thumb/2/22/United_States_Shale_gas_plays,_May_2011.pdf/page1-1650px-United_States_Shale_gas_plays,_May_2011.pdf.jpg)

the available technologies. Thus, in 1975 the interdepartmental committee for raw materials was established in the USA that focused on formation of a reliable chain "exploration – production – processing – consumption – use of raw material wastes." That time the USA also announced six national programs, one of which envisaged development of its own resource base. One of such resources was shale gas [5].

The first results of shale play development permitted to expect growth of the shale gas production, although initially the shale gas production was much lower than production of traditional gas. Thus, gas concentration in shale plays of the USA ranged from 0.2 to 3.25 bcm per square kilometer. With the yield rate of 20%, the recoverable gas reserves were assessed at 0.04–0.6 bcm per square kilometer, which is 50–100 times less than for the traditional gas fields. In addition, the commercial development of the shale gas plays required extensive geological surveys and drilling of dozen thousand wells during 7–10 years. Nevertheless, the oil and gas companies engaged in shale gas development continued their business.

Experience of the USA in shale development has shown that each shale formation requires individual approach, possesses unique geological conditions and operational peculiarities, and faces different problems that may arise in the course of production.

3 Shale Gas Reserves

In the 1970s during the energy crisis and aggravation of the energy security issues, the US government seeking the likely way out recollected once again about the shales. As a result of prospecting works, there were four major shale formations found – Barnett (Texas), Haynesville (northwest of Louisiana and Eastern Texas), Fayetteville (Arkansas), and Marcellus (Pennsylvania, West Virginia, New York, and Maryland) as well as others covering dozens of thousand square kilometers and containing enormous shale gas reserves (Fig. 2). The main shale plays are described in the Table 1.

As the parent land of the shale gas production is the USA, the attention of everybody was focused, quite naturally, on the reserves of this hydrocarbon in the

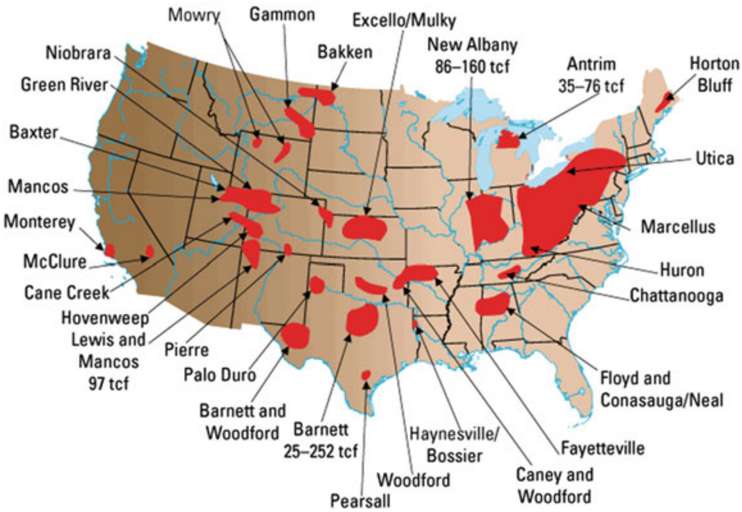

Fig. 2 Major shale gas formation in the USA (http://www.ehelpfultips.com/shale%20gas%20map%20of%20the%20united%20states.gif)

Table 1 Main shale gas formations in the USA

Name	State	Depth of occurrence, m	Layer thickness, m	Reserves, bcm
Barnett Shale	Texas	1,900–2,600	30–180	760.5
Woodford Shale	Oklahoma	1,800–3,300	36–66	180.99
Haynesville Shale	North and East Louisiana, Texas	3,200–4,000	60–90	296.5
Fayetteville Shale	Arkansas	3,000–21,000	7–60	256.9
Marcellus Shale	Pennsylvania, West Virginia, New York, and Maryland	1,200–2,600	15–60	126.8

USA. In 2008 according to the assessments of the Energy Information Administration (EIA) of the US Department of Energy, the proved reserves of shale gas in the country made 866.6 bcm.

According to the report of the International Energy Agency (IEA) presented in 2009, after improvement of the applied technologies, the recoverable shale gas reserves in the USA have shown the 51% growth. As a result, EIA assessed the proved gas reserves in the USA at 58.7 tcm. However, in December 2010 EIA after respective adjustments decreased, the proved shale gas reserves in the country and, as of the late 2009, they made only 1.63 tcm.

The US Potential Gas Committee consisting of specialists in shale gas production announced about fundamental reassessment of the natural gas reserves in the USA, having increased them from 36.8 to 52.0 tcm, out of which nearly a third of the projected reserves accounted for shale gas (12–17 tcm). In 2009 this committee issued a new comprehensive report about the amount of gas trapped in the shales where the shale gas reserves were evaluated at 51.9 tcm. The US Department of Energy in its report projected the increase of the shale gas production to 113 bcm in the nearest future.

Regardless of the uncertainties concerning reserve estimates, many international organizations in the USA persisted that the USA possessed from 17 to 108 tcm of shale gas. The proved shale gas reserves make 24 tcm, out of which 3.6 tcm are technically recoverable, while the consumption of natural gas in the USA is equal to around 650 bcm per year.

According to the EIA's 2011 Annual Energy Outlook, the shale gas reserves made 72 tcm, out of which 24 tcm were technical recoverable reserves. However, later on the forecast for the technically recoverable shale gas reserves was decreased to 13.6 tcm.

In early 2012 the Energy Information Administration (EIA) of the US Department of Energy lowered its assessments of the shale gas reserves to be extracted by 40%. In the same year IEA published new assessments of the shale gas reserves, putting them at 208 tcm. While speaking about the shale gas reserves, the total geological reserves or technically recoverable reserves are often meant. And here no reference is made to the proved shale gas reserves.

The major explored shale hydrocarbon resources are found in the North America: in Texas (Barnett play, Eagle Ford oil play), North Dakota (Bakken oil play), Montana, Michigan, Oklahoma, Alabama, and Arkansas. The resources of the shale gas (recoverable) in the surveyed basins are estimated at 13.5 tcm of gas and 4.5 billion tons of oil.

The recent surveys of the shale gas plays in 48 states of the USA have shown that the technically recoverable reserves are estimated from 7.1 to 24.4 tcm. The wide scatter of figures indicates that regardless of long-time investigations, the reserves are assessed only roughly.

4 Shale Gas Production

The shale gas production got its start in the late 1990s and has increased gradually by the first decade of the twenty-first century. Survey and prospecting works lasted for several years. In 1998 the USA produced 8.3 bcm of shale gas. The development of the Barnett Shale play in the north of Texas went on. The geological reserves were assessed at 590 bcm, while the proved recoverable reserves were at 59 bcm [6]. Company Chesapeake Energy, the operator of this play, had invested around US$ 30–40 billion into its development.

The conducted surveys have shown that the shales occur here at a depth of 450–2,000 m covering an area of 13,000 km^2. The layer thickness varies from 12 to 270 m. The methane level in the play amounts to about 0.3%.

In 2002 the US company Devon Energy drilled the first horizontal well in the Barnett play, thus, launching the shale gas production at scale in the USA based on the new technology [7]. In the same year, the shale gas production technology was upgraded to combine vertical and directional drilling. Combining the two processes – vertical and directional drilling – with the multistage fracking became the new achievement in the shale gas production which permitted to lower the cost of production and to increase the attractiveness of shale play development.

The US companies learned gradually how to handle the shale structures and acquired new experience of working in shale plays. In 2003 there were produced 14.7 bcm of shale gas, permitting the US companies engaged in this hydrocarbon production to make projections of future production volumes.

From 2005 the shale gas production in the USA had increased sharply, and the shale gas contributed much to the gas production growth in the USA. Around 70% of the shale gas was extracted in the Barnett play. Already in 2006 the production of shale gas in the Barnett play from 6,080 wells made 20 bcm, and in 2007 the USA produced 34 bcm of shale gas.

In 2008 there was a real breakthrough in the shale gas production in the USA which was facilitated by the following factors: First, on the eve of the world financial crisis, the hydrocarbon prices reached their maximum. The natural gas production in the USA has surged all at once, demonstrating the highest growth rates for the recent quarter of the century. And the shale gas gave the greatest growth. Second, the effect of accrued investments in the shale production sector and reduction of the traditional gas potential came into action. Third, the improvement of production technologies and application of new materials allowed for cost reduction. Therefore, the "shale revolution" in the USA started, in fact, not after appearance of the really important advanced technologies but after the gas cost reached nearly 500 US dollars per thousand cubic meters. So, the production of shale gas became economically beneficial [7].

Owing to the vigorous increase of the shale gas production, called in mass media the "gas revolution," the USA in 2009 became the world leader in gas production extracting 745.3 bcm, and the unconventional sources (methane from coal formations and shale gas) provided over 40% of this output.

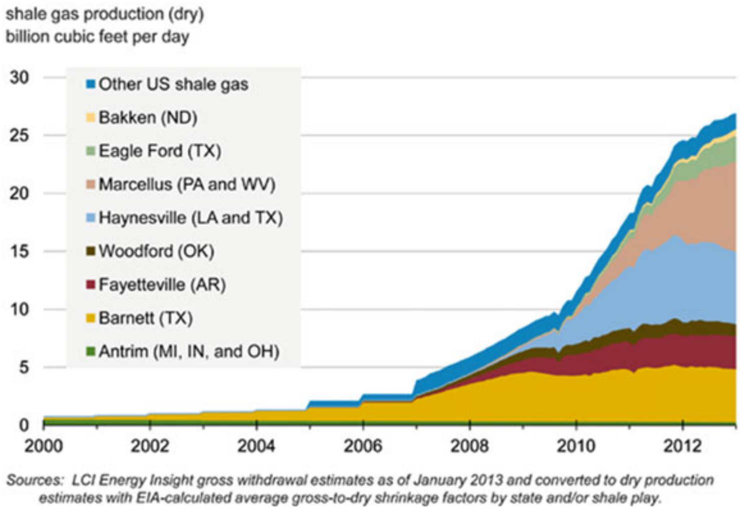

Fig. 3 Shale gas production in the USA by geologic formation (https://upload.wikimedia.org/wikipedia/commons/2/27/US_Shale_Gas_Production.jpg)

As a result, already in 2010 the shale gas production made 132 bcm. In the 2003–2010 timeframe, more than 190 thousand wells were drilled in the USA, out of which nearly the half were abandoned due to their unsuccessful results. However, the oil and gas companies continued drilling works, and by 2009 there were drilled 1,658 horizontal wells [8] which permitted to increase the shale gas extraction. Moreover, some amendments were made in the subsoil use act that removed constraints for application of the hydraulic fracturing technology with the use of chemical agents without which the companies were unable to cut their costs.

The major US companies, such as Chesapeake, Apache, Devon Energy, and Noble Energy, were the leaders in the shale gas production (Fig. 3). In 2012 Chesapeake extracted 32 bcm. The main asset of this company is the Barnett play as well as Haynesville and Marcellus plays. The company Apache produced 24 bcm followed by Devon Energy and Noble Energy [9].

The rapid increase of the shale gas production in the US territory was facilitated by numerous factors, such as the enormous economic potential, the immense reserves and vast sparsely populated areas, the availability of well surveyed plays, the permanently improving drilling technologies, the proximity to gas consumption locations, the preferential taxation, the developed gas transportation infrastructure, and the strong endeavor to attain energy security based on its own resources. A powerful stimulus for shale gas production in the USA was preferential taxation that is not found in Europe.

Having sharply increased the shale gas production, the US companies lowered the gas prices, thus, putting themselves in a complicated situation. This led to significant changes in the country-wise distribution of the world gas market and by early 2010 to excessive shale gas supply in the market.

Regardless of these complications, the US companies continued shale gas production. According to the Energy Information Administration (EIA) of the US Department of Energy, the shale gas production in 2010 had grown to 132 bcm. In 2011 the shale gas production was assessed at 150 bcm, or 15% of the cumulative gas output in the world. In 2012 there were produced 260 bcm of shale gas, in 2013 it reached 319 bcm, and in 2014 it reached 350 bcm [10]. As a result, the USA was the only country in the world that started gas extraction from shales at industrial scales. In 2012 the shale gas provided around 30% of the total gas output in the USA.

There are fundamental reasons why the "shale revolution" in the USA became possible. Comparing the dynamics of gas production in the USA with the adopted solutions for stimulation of the unconventional gas production, it bec*omes* clear that the achievements in the shale gas production are rooted in the decisions taken by the US authorities in the 1970s–1980s. And the key factor here is the tax legislation – the oil and gas companies engaged in shale gas production were granted the tax credit. In fact, this allowed for considerable reduction of the production costs and, accordingly, attraction of additional investments into development of shale gas plays.

The shale gas production spurred the development of the gas transport infrastructure. In 2008 the pipeline system designed to supply shale gas from the Fort Worth basin to the gas pipelines on the Mexican Gulf coast of the USA accounted for 11% of all new gas transportation capacities. In 2009 the capacity of gas pipelines connected with the shale gas plays continued its growth. The projects were implemented that ensured better conditions for shale gas delivery. In 2013–2015 the growing shale gas production encouraged further development of adjacent productions involved in development shale gas plays.

5 Forecast of the Shale Gas Production

The USA is persistent in its endeavor to keep its leadership in the shale gas production in the next decade. In the 2011 Annual Energy Outlook the shale gas, for the first time since its production has been launched, was given great credibility. The first projections based on the growth rates of the shale gas production that were made – in two decades its production in the USA shall double and reach 473 bcm and by 2035 – 45% of all gas produced in the USA will be extracted from shale plays [11].

According to the Ernst & Young forecasts, by 2035 the shale gas production in the USA will reach the level of 342 bcm or demonstrate a nearly fourfold increase compared to 2009 [12]. Here EIA assumed that by 2030 the shale gas would take only 7% of the global gas market. As a result, EIA believes that the escalation of the shale gas production in the next 25 years could only offset the reduction of its inflow from other sources.

6 Shale Gas Attracted Big Business

In the USA the gas trapped in the shale formations was extracted mostly by small independent companies – classical venture companies implementing risky innovative projects. However, having developed and applied in practice the advanced technologies of directional drilling and hydraulic fracturing (fracking), these companies succeeded to increase sharply the shale gas production at a relatively low, as was asserted by the representatives of these companies, cost, and big business rushed into this sector. The large oil and gas corporations that earlier preferred to observe the actions of Chesapeake Energy and its colleagues as bystanders started moving to this business.

In 2009 British BP invested 1.3 billion US dollars for 50% interest in the joint venture that intended to extract the shale gas in the Haynesville play. Italian Eni also invested into the US companies engaged in the shale gas production. In the same year ExxonMobil, the world's largest oil and gas corporation, purchased the US company XTO Energy possessing technologies and professionals for 41 billion US dollars, including covering of debts for 10 billion US dollars, which was the second largest producer of shale gas in the USA which reserves were estimated at over 1.5 tcm.

In 2010 the French Total established the joint venture for developing the Barnett Shale play with the leader in this business – company Chesapeake Energy. They extended their services keeping in mind that in the future the backup and maintenance services may guarantee profits for them for many years ahead. The French company paid around 2.25 billion US dollars for 25% interest. Earlier other oil and gas giants, such as British Petroleum and Nordic Statoil Hydro, entered into the partnership agreements with Chesapeake. Norway invested 3.4 billion US dollars. In February 2010 the Japanese company Mitsui Bussan invested 5.4 billion US dollars into development of the Marcellus Shale play in Pennsylvania. This project is evaluated at 25 billion US dollars. Summing up the above, only in the first half of 2010 the largest world fuel companies spent 21 billion US dollars for purchase of the assets in the shale gas production field [13]. Over 2005–2010 period, the transactions related to merger and takeover of companies involved in the shale gas production projects earned 100 billion US dollars [14].

In mid-2011 the largest mining company BHP Billiton (Britain and Australia) announced about purchase of the US corporation Petrohawk Energy for 12.1 billion US dollars. These assets were purchased to get access to the shale gas reserves in Texas and Louisiana. Earlier, in February 2011, BHP purchased the interest in the shale gas play in Arkansas of Chesapeake Energy for 4.75 billion US dollars.

The interest of large oil and gas companies to the shale gas production was enhanced by the data on this hydrocarbon production. In 2014–2015 the USA was the leader in shale gas production that as before remained one of the main factors influencing the global gas market.

7 Shale Gas Cost

One of the key issues faced by all oil and gas companies engaged in the shale gas production is the cost of shale gas. The US companies promoting widely their success in the shale gas production focused on the low cost of this gas. The US second largest producer of natural gas specializing in shale gas extraction – company Chesapeake Energy – made public the shale gas production costs making, on the average, US$ 99 per 1,000 cu. m. Such declarations promised the real "shale revolution" in the gas market. Such costs allowed for making projections of the shale gas export to the foreign markets. Adding here the costs of gas liquefaction and transportation to Europe, the total gas price reached US$ 200 per 1,000 cu. m which was economically efficient [15].

Meanwhile, the experience of the shale gas production shows that the situation in this business is not so cloudless. Moreover, the costs of the shale gas production call many questions, which is the reason to doubt the reliability of the supplied data.

The assessments of the shale gas plays should take into account the fact that the amount of accessible gas in the shales is directly proportionate to the shales thickness. The most economically effective are considered the "fragile" shales with a high level of silicon dioxide. These plays contain natural bends and fractures. This very fact explains why the Barnett play is highly productive. In fragile shales the less intensive fracking is possible.

At the same time, the low gas concentration in rocks explains the quick decline of drilled wells. As a result, the optimistic forecasts underestimate the shale field decline rates. The shale gas is extracted in great quantities only in the first year of drilling, while later on the production declines and is maintained at a lower level. To keep the gas production at a stable level, the companies should permanently drill new wells. In the largest shale gas play Barnett in Texas, the well decline rate by the second year of production made 37%, on the average, and by the third year 50% compared to the first year. This means that the efficiency of shale gas production requires permanent drilling of new wells and maintaining the operating parameters of the drilled wells. As a result, the real cost of the shale gas production with regard to all expenses on land site lease, drilling of a great number of wells which yield declined sharply already in a year, and creation of the respective infrastructure is evaluated at 242–282.5 US dollars per 1,000 cu. m. So, the data on the shale gas production costs for companies vary within a wide range – from 130 to 400 US dollars per 1,000 cu. m.

8 Conclusions

In the 2013–2015 timeframe, the shale gas production rates in the USA remained high. Moreover, the quicker than it was assumed, earlier growth of the shale gas production in the USA led to spot price collapse on the American continent and in

Europe. The gas underdelivered to the USA due to the domestic consumption growth was redirected to Europe that affected the deliveries of the Russian company "Gazprom" which prices exceeded significantly the market quotations.

The shale gas and oil production in industrial scales is conducted only in four world countries: the USA, Canada, China, and Argentina. But in the last three countries, the volumes of production are meager. Thus, the USA is the only country producing significant amounts of unconventional hydrocarbons. According to British Petroleum estimates, by 2030 the USA will produce 63% of gas from shale and coal formations, and by forecasts of the International Energy Agency by 2035, this figure should grow to 71%.

The increase of the shale gas production will permit the USA to minimize the import of natural gas and to purchase it only from Canada. The terminals for the imported liquefied gas available in the USA may be used to cover the current needs during seasonal maximums, while the accomplishment of the US strategy to supply shale gas to the European market could become an additional stimulus for extension of this hydrocarbon production.

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Shale Gas in Europe: Reserves, Production, and Perspectives

Igor S. Zonn and Aleksander V. Semenov

Abstract The history of the commercial shale gas production in Europe is not long. But still the issue of shale gas production is in the focus of attention in many European countries. On the one hand, this is connected with the tougher competition among the countries exporting natural gas and, on the other hand, with the endeavors of many gas-importing countries to diversify the sources of hydrocarbons and at the same time to purchase them at a lower price.

Keywords Europe, Production, Reserves, Shale gas

Contents

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1 Introduction

The phenomenon of the so-called shale revolution advertised widely by the US companies was not overlooked in energy-dependent Europe. Moreover, the US experience and successes in the shale gas production stirred great interest in many European countries that started developing plans for extraction of their own reserves of shale oil and gas. Primarily, the European countries saw the opportunity to diminish their dependence on gas supplies via pipelines, first of all, from Russia.

In 2009 EU launched the project "Gas Shales in Europe" to be implemented within 3 years. It envisages large-scale surveys of shale plays in Europe. This project is sponsored by a group of companies, including Statoil, ExxonMobil, Gas de France, Wintershall, Vermillion, Marathon Oil, Total, Repsol, Schlumberger, and Bayerngas. In November 2012 the European Parliament by majority votes gave permission to the EU countries to produce shale gas and did not support the proposal of imposing moratorium on the fracking technology application. In December 2012 the decision on renewal of the shale gas production was passed in Great Britain, and in January 2013 Chevron applied for permission for shale development in Lithuania.

At the same time, the policy of the European countries in shale gas prospecting and production lacks some single approach. The countries pursue their own interests and rely on their own assessments of possibilities of shale play development. Perhaps, for this reason by 2013 no unified strategy in respect of this technology of gas production in united Europe had still existed [1].

The European countries like many other countries that showed interest in shale gas plays faced the lack of reliable and accurate data on the reserves of this hydrocarbon. This gave rise to many speculations concerning the shale gas reserves and appearance of some fantastic projections about future volumes of shale gas production. As a result, Europe has no accurate data about the shale gas reserves, but only some rough estimates varying widely.

2 Shale Gas Reserves

In 2009 the "shale boom" reached Europe. The interest to this hydrocarbon was supported by availability of enormous resources of gas-containing shales and also the endeavor to diversity the sources of gas supply to the European market. Herewith, the European countries have no accurate assessments of the shale gas reserves. The multiple estimates of the shale gas reserves were usually provided by the representatives of foreign, primarily US, companies and international organizations. Thus, according to International Energy Agency (IEA), Europe may have up to 16 tcm of shale gas, while according to the US statistics agency at the US Department of Energy [2], this figure may be as high as 18.1 tcm. At the same time, by estimates of the US Energy Information Administration, the technically

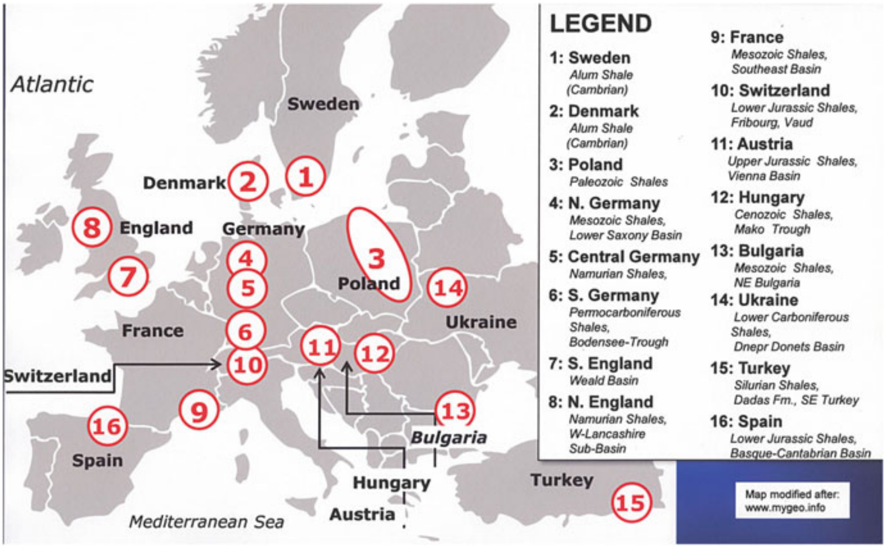

Fig. 1 Shale gas opportunities in Europe (http://www.netlabgmbh.de/ShaleGas%20Europe.jpg)

recoverable resources of shale gas make 5.3 tcm. Based on such data, there were made assumptions about the opening opportunities for Europe to change drastically its gas market structure having reduced significantly the dependence on hydrocarbon supply from Russia, Near East, and North Africa. Thus, in the recent years, the gas consumption in the European countries made around 550 bcm. After respective estimates, it was concluded that the shale gas reserves were sufficient to meet the needs of Europe for 30–35 years.

Regardless of the lack of geological survey data and insufficiency of information, it is assumed that such countries as Poland, Germany, the Netherlands, Hungary, Sweden, Great Britain, and France may have up to 15 tcm of shale gas that in the future may be developed in industrial scales (Fig. 1).

According to projections, the largest shale gas plays are found in Poland and Northern Germany. For example, the shale gas reserves in Germany are estimated at 2.2 tcm, in Poland – 5.2 tcm or 29% of the cumulative reserves in Europe, and in France – 5 tcm. These data need further verification which requires drilling of many wells. And only a small fraction of these resources may prove cost-effective in the future for industrial-scale production.

3 Shale Gas Production

The recent years have been marked by close attention of US companies to European countries that are considered as one of the potentially profitable regions for shale gas production. In April 2010 the US Department of State launched the Global

Shale Gas Initiative called to assist the world countries in finding and developing the unconventional gas sources applying safe and cost-effective techniques. At the same time, this program supports the economic and commercial interests of the USA.

It is highly probable that in some parts of Europe the shale plays may be less convenient for development than in the USA. As a result, it will be very difficult for Europe to repeat the success of the USA because the West European shale plays are smaller, contain less gas, and occur deeper. At the same time, they have a high clay content which impedes the application of the fracking technology. Thus, in Poland the shales occur at a depth of 3–4.5 km, which exceeds much the depth of shale gas occurrence in the USA. Accordingly, already today it can be said that the shale gas production in Europe will be more costly than in the USA.

Europe only starts the trial drilling and it is too early so far to speak about industrial-scale production. In 2010 Europe launched nine projects of shale gas prospecting, of which five projects are implemented in Poland. The cost of drilling of one prospecting well there was US$ 20 million. In general, the cost of the shale gas production in Europe will be several times higher. It is still difficult to forecast the role of shale gas in Europe as there are no operating wells so far. Only after drilling wells it will be possible to assess the conditions of geological structures and their perspectives in terms of commercial feasibility.

4 Difficulties in the Shale Gas Production

There are some peculiarities interfering with the development of unconventional gas sources in Europe. First of all, these are issues connected with the geological structure of the plays. There are no two shale gas plays in the world with identical characteristics; likewise, there are no two identical shale formations. Each of them has its unique features. They may occur at different depths, differ by the volume and other parameters. The shale gas prospecting and production are the process that requires much time and costly technologies. Therefore, the production technology in each play shall be modified with regard to its particular features. This may lead to the increase of the play development time and related costs.

There are also other problems faced by the companies intending to extract shale gas in Europe, such as high population density in European countries that makes rather problematic the access to shale plays which development may result in groundwater pollution.

The shale gas production in Europe may be a much more complicated venture than in the USA due to likely negative environmental consequences and some other difficulties. First of all, the relationships with the population and controlling authorities will not be easy. The main shale gas plays in the USA locate in the sparsely populated areas where oil and gas have been produced for many decades. According to the US laws, the owner of a land site where mineral deposits are found may expect high revenues from rent. In Europe the shale gas will be extracted nearby the densely populated areas. Moreover, in Europe the pay for the mineral deposit production is directed to the state. In this context, the companies engaged in shale gas production may face the opposition of the population and legal suits against drilling of wells.

All these factors lead to a conclusion that one should not expect the repetition of the US "shale revolution" in Europe. In Europe there are legislative restrictions preventing the companies from launching the shale gas production in the scales observed in the USA.

Development of the shale gas production may require serious alterations in taxation of this industry in the countries planning to conduct surveys of these resources. Regarding the potential of the shale gas plays, the new players, including Poland and Ukraine, may appear in the oil and gas industry.

Therefore, the low level of geological exploration, the lack of free access to shale plays due to high population density, difficulties with obtaining licenses to development works, the absence of a legal and tax base, hazards of breaking the integrity of underground structures, and the lack of the US technologies in the European companies, all these factors are obstacles for the shale gas production in the European countries.

5 Prospects of the Shale Gas Production

The flow of news from the USA stirred discussions in Europe regarding the prospects of the shale gas production. One of the key issues being in the focus of attention in Europe is whether the shale gas will substitute in the future the natural gas supplied by pipelines.

Even if the shale gas reserves in Europe are confirmed, it is quite unlikely to expect rapid growth of its production. The main skepticism in respect of forecasts of the shale gas production in Europe takes its origin in many problems around this venture, primarily, the fact that the shale gas reserves require careful studies. All data about the shale plays present only rough and unconfirmed estimates. In addition, the population density in Europe is much higher than in the USA. This will cause the conflict of interests between the oil and gas companies, on the one side, and the public that in its majority pushes back against the shale gas production, on the other. Considerable investments are required for creation of infrastructure and development of shale plays. Thus, the EU countries have a small quantity of gas wells. Moreover, the European countries do not have the appropriate equipment and the personnel to organize gas production in such scales. Meanwhile, the shale gas production requires drilling of a great number of wells, and the wells should be drilled permanently as, unlike the natural gas deposits, the well yields in shales decline by 70–90% by the end of the first year of operation. Consequently, in Europe the drilling rates should be increased multiply which needs time and additional costs.

And, at last, we should not neglect the wide public movement against the shale gas production. The ecologists in the European countries organize protest meetings demanding not to launch the shale gas production. This is connected with drilling works and environment pollution which get under the European bans.

If we take into consideration the current realities of geological surveys and existing difficulties connected with the shale gas production, it can be said that the role of shale gas in ensuring the energy security of Europe will be much more modest than declared by some politicians and experts. Shale gas may be very useful for Europe, however, quite unlikely that the European gas market will witness any shale revolution and will be able to abandon completely its dependence on the Russian energy sources. In this regard it is difficult to assume that shale gas will become the panacea for energy independence of Europe, rather the shale gas may be considered, more precisely the whole problem, as a tool with which Europe will assert its geopolitical and economic interests in relations with Russia.

Regardless of rather obscure prospects, a powerful PR-campaign in support of the shale gas production was unrolled in Europe. This boom around the shale gas is created artificially and is supported by major energy companies. The European countries are pressed strongly by the US administration that is targeted to promote the interests of the US companies engaged in the shale gas production. The idea that the natural gas extraction from unconventional fields will lessen the EU dependence on exporting countries is pushed energetically. The shale gas production will lead to serious geopolitical changes on the continent. The growth of the shale gas extraction as well as supply of liquefied gas from Qatar at dumping prices will cut significantly the gas supply by Gazprom; thus, the European countries are expecting to reduce their dependence on gas supply from Russia.

Based on rather approximate estimates of reserves, the projections concerning the shale gas production in Europe are also only rough (Fig. 2). Accordingly, the extraction of shale gas in Europe cannot start earlier than in 2025. So, the role of shale gas in EU may be quite minor. The estimates of shale gas production vary from 10 to 30 bcm, and then only in perspective. These are small figures and they are unable to influence seriously the situation in the European gas market. And especially since the main limiting factors here are the strict European laws and safety requirements. The most optimistic forecasts do not go over 40 bcm per year by 2030 or 5–7% of the volume of planned natural gas consumption in Europe.

In fact, the technologies of the shale gas extraction are rather traditional and their specific feature is in their adaptation to the conditions of particular plays. It is not a fact that the US technologies of shale gas production may be applicable in other countries, both for financial and operational-technological considerations.

The large-scale development of shale gas plays in the EU countries is rather doubtful, at least, in the midterm perspective. The production costs are high and may be equal to US$ 100–200 per 1,000 cu. m in well mouth. According to other estimates, the shale gas production in Europe will be more costly than in the USA and may reach US$ 350 per 1,000 cu. m.

Some legal, tax, and environmental constraints should be also added here. The poor geological survey of reserves, high production costs, and the lack of own

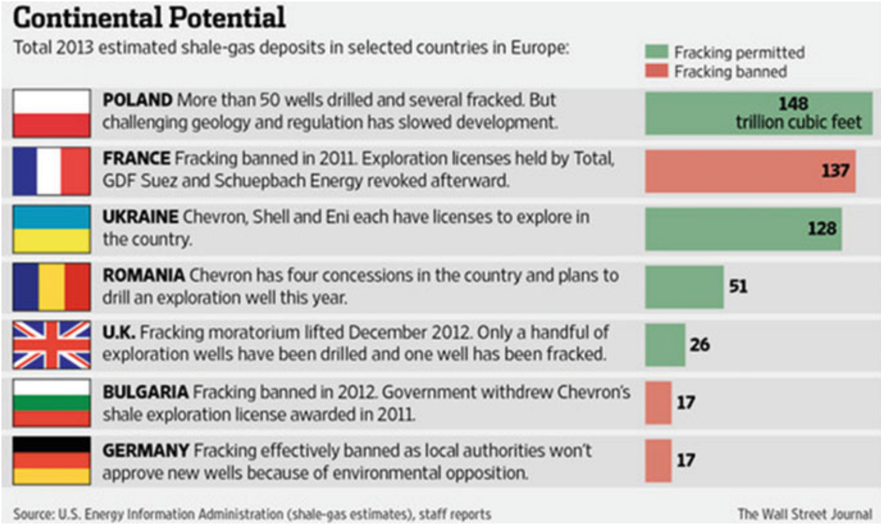

Fig. 2 Shale gas deposits in selected countries in Europe (https://si.wsj.net/public/resources/images/WO-AR812A_EUSHA_G_20140326183913.jpg)

extraction technologies [3] will make the shale gas production in Europe much more difficult. Consequently, in the near future, the shale gas in Europe will be treated as backup and not the main source of gas supply.

The European environment protection laws which are much tougher than in the USA will play their role here. In the USA the effect of the fracking technologies requiring great amounts of water and chemical agents on the ground waters is being studied. This issue remains acute and from time to time it is raised by ecologists. Obviously, in Europe, the protests of the "green" and initiative groups will be more energetic than in the USA.

6 The US Role in the Shale Gas Production in Europe

There has been no any certainty so far about the prospects of the shale gas production in Europe although the major oil and gas companies have invested cumulatively about dozens of billion dollars into purchase and initial development of shale plays seeking to "stake out" a place in the market and to obtain licenses for prospecting and development of the most promising plays. These companies assume that the production technologies will be improved and it will be possible to speak about a considerable progress in choosing the natural gas production techniques. In Europe about 40 companies undertake surveys of the shale gas plays. The US companies ConocoPhillips and ExxonMobil as well as the British-

Dutch Shell purchased licenses to the shale gas extraction in Poland, Sweden, and Germany.

The Washington's strategy for energy diversification of EU was targeted to reduce the dependence of the European states on the Russian hydrocarbon supply by creating alternative routes for natural gas transit from the Caspian and Central Asian Region. However, after the beginning of the "shale revolution," the major US oil-producing transnational corporations have shown interest to development of shale plays directly in Europe, thus seeking to diminish the hydrocarbon supply from Russia.

So far the Old World has been discussing the prospects of the shale gas production that will radically change the perspectives of the energy market development in the USA. But the effect of the "shale revolution" on the European energy market may be described more likely as an evolutionary process. Only a small fraction of these resources may be cost-effective in the future for commercial scale production. More than 50% of all assessed reserves of shale gas in Europe making around 10% of the world reserves are found in two countries – Poland and France – which are followed by Germany that also possesses the considerable shale gas reserves.

The most active advocates of the shale gas idea are the US-oriented countries. The peak of the shale gas production is reached very quickly, but its decline goes on at an equally rapid pace.

The plans for meeting the growing needs of the EU energy markets include construction of gas pipelines in the eastern direction, development of the infrastructure for take-in and use of LNG, and introduction of energy-effective technologies. According to the IEA forecasts, by 2035 the demand for gas in Europe will show a 20% growth which may enhance dependence of the European countries on gas import.

7 Conclusions

Based on the foregoing, it can be said that in the near 1–2 decades, it is quite unlikely that shale gas with its rather modest share in the energy balance will influence significantly the European gas market. Much time should pass until we see the tangible effect of the "shale revolution" on the market. So, Europe goes on to stake on the natural gas supplied by pipelines.

But this does not mean that the technologies of shale gas production and likely ways to mitigate negative environmental consequences should not be investigated. These issues should be permanently in the focus of attention of the leading oil and gas companies. Quite another thing is that the issues related to the shale gas production and its perspectives should not be carried over to the political sphere. It is obvious that in the long-term perspective the Russian gas will dominate in the energy balance of the European countries. In 15–20 years, when new technologies may appear, the share of the natural gas in the market may be reduced, but its complete substitution with shale gas is highly doubtful. Besides, the increase of LNG supply expected in the nearest decades as well as construction in Europe of additional terminals for LNG import may also subdue the interest of the European countries to development of shale gas plays.

The difficulties with the shale gas production in the absence of the accurate information about its reserves as well as environmental risks may also force to postpone the shale gas production in Europe for the uncertain time period. Therefore, it can be said that even in case of increase of the shale gas production, the drop of hydrocarbon prices in Europe will be not as rapid as in the USA. Accordingly, long waiting for the progress in the shale gas production creates prerequisites for ongoing high interest to further development of the pipeline transport in Europe and for maintaining interest to delivery of liquefied natural gas.

In general, the effect of shale gas on the energy markets in different countries will vary greatly governed by such factors as the national energy strategy of a particular country, the degree of its dependence on energy import, the projections of gas demand growth, the cost of alternative rivalry supplies of hydrocarbons, and the attitude to them of the public. But these factors may become decisive for small and medium independent companies oriented to development of the shaping shale gas sector in Europe. Finally, the pace and feasibility of shale gas play development in Europe will be controlled by numerous considerations, including environmental and social, the hydrocarbon prices, demand in gas and also taxation and regulation regimes.

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European Policy and "Shale Revolution"

Sergey S. Zhiltsov and Aleksander V. Semenov

Abstract The European countries started focusing more attention on the shale gas in the late twenty-first century when the first data on shale gas production came from the USA. Initially, many European countries found that they had no accurate data about the shale gas reserves and lacked adequate infrastructure, professional personnel, and technologies. In many European countries, the prospects of shale gas production raised serious concerns, especially among ecologists, due to its negative impact on the natural environment.

Keywords Ecology, European countries, Production, Reserves, Shale gas, Technologies

Contents

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1 Introduction

Many European countries cherished hopes that the shale gas would bring them energy independence. The most radically minded optimists went even further asserting that the consequences of the "shale revolution" would help to liquidate the formula connecting the prices of natural gas and oil in the world market. And in this case, the main losers would be the major natural gas exporters, such as Russia, Algeria, Iran, Bolivia, Qatar, and other Persian Gulf countries.

The European countries seeking to develop shale plays should remember that it is easy to discover shale reserves, but it is much more difficult to extract them. The shale gas production may be cost-effective in long perspective only at the growing gas prices. Besides, it requires great investments through the whole period of shale play exploitation due to the permanently growth of well drilling and fracking operations.

The European countries made public the estimates proving the possibilities to attain energy independence for many decades ahead based on the shale gas production. Many speculative and timeserving declarations were made to heat up this problem instead of its fundamental scientific research. Opposing the shale gas to the hydrocarbons supplied by Russia to Europe acquired political dimensions.

It had to be admitted that the shale gas production projects in Europe due to more complicated geographical conditions are more costly than that in the USA. At the same time, the successful implementation of shale projects in Europe is jeopardized by such factors as complex geological conditions, high population density, strict environment protection regulations, insufficiency of financial stimuli, and tax privileges. As a result, it can be concluded that the shale gas can play its role in Europe, but not earlier than in 5–10 years [1].

2 Europe in Search of Energy Independence

The operation of foreign companies offering their services on shale gas production in Europe is easier in the absence of the unified European legislation regulating this business. Each European country has its own legislation regulating the prospecting and extraction of traditional hydrocarbons, but it does not cover the shale play development and application of related technologies. In March 2011 EC published the Energy Action Plan envisaging transition by 2050 to competitive and low-carbon economics. However, this document does not mention the shale gas.

In general, taking into consideration the differing interests of European countries, it seems quite unlikely that they will develop the unified European legislation. Perhaps, the shale production issues will be included into the next legislative documents of the European Union.

The strategy of the USA pressing on the states yielding to the US influence has been well proven, including in the shale gas production area. First, the USA brings the news about immense shale gas reserves in a country depicting herewith the picture of complete energy independence, and after this the US companies promise billions of investments. But most likely, everything will end up with the trivial sale of technologies and services.

The wide-scale geological prospecting works should be conducted to obtain the reliable information about the shale gas reserves in Europe. Based on such information, the earlier published data may be adjusted both to the greater and lesser side. Consequently, until this moment, all statements made in the European countries about enormous shale gas potential and quick growth of its production are no more than simple declarations. And the more so as the shale play development requires usually the greater volume of services compared to development of traditional oil and gas fields. As a result, the inadequate production capacities and poor development of the services segment in the oil and gas industry and shortage of the equipment and professionals are the main factors impeding the accelerated growth of the shale gas production in Europe.

Sweden cherishing the idea of becoming a large shale gas producer invited Shell that in 2009 started prospecting drilling in this country. However, already in early 2011, the company declared that the prospects of finding shale plays in Sweden are practically nil.

Hypothetically, the considerable shale reserves may be found in the Netherlands. Good prospects in this respect have France, Germany, and Austria. The Austrian company OMV intends to initiate shale surveys nearby Vienna. Romania and Serbia are planning to launch geological prospecting works (Fig. 1).

The shale factor is already producing its effect on the energy policy of the European countries forcing them to revise their approaches to ensuring their energy security. Thus, in early 2013 Romania called off moratorium on application of fracking technology in shale gas prospecting and supported geological surveys of shale gas. The authorization to performance of such works was issued to company Chevron [2]. However, already in early 2015, Chevron closed the shale projects in Romania and later on in Poland.

Following many European countries, Turkey also joined the shale rush. Ankara showed great interest to this hydrocarbon resource. According to preliminary assessments, the shale gas reserves in Turkey may vary from 6 to 20 tcm. The report of the Turkish Association of Petroleum Geologists put the shale gas reserves in the country at 1.8 tcm. These figures cover the reserves in Thrace and Southeastern Anatolia, while the shale gas resources are also available in Eastern Anatolia, Black Sea region, Ankara, and Tavr mountains.

At present company Shell started shale gas development in the southeast of Turkey after signing in February 2013 the Agreement on Cooperation with the

Fig. 1 European shale gas basins (http://clauswarum.blogspot.ru/2014/07/shale-revolution.html)

National Petroleum Company of Turkey. The Canadian Trans Atlantic Petroleum is also operating in the Turkish territory.

Developing their shale plays, the European countries face numerous problems. In December 2012 Great Britain issued permits to some companies for continuation of test drilling in the Lancashire County in the west of the country. Later on they were suspended due to underground shocks. However, in August 2015 the British government once again focused attention on the shale gas production. The Department for Communities and Local Government was entitled to interfere into consideration by local authorities of applications for shale play prospecting and shale gas extraction. This decision fits the policy pursued in Great Britain that is targeted to attracting oil and gas companies to participation in shale projects.

In Hungary several wells were drilled, but they were recognized non-perspective and the program of shale gas production was closed.

In July 2015 the Dutch government adopted the decision on banning the shale gas production. This ban was declared for 45 years. The Dutch government explained that such decision was taken because of the lack of accurate data on the shale gas reserves and availability of negative environmental impacts. Great attention of the Dutch government to this issue was connected with the complicated situation in the fuel and energy complex of the country. In 2014 in the Netherlands the gas production dropped by 19% which forced the government to seek alternative sources – shale gas production.

In March 2015 the Dutch-British Shell had frozen surveys of shale gas in SAR. The main reason here was the lack of reserves fit for commercial-scale development.

In August 2015 Total refused from implementation of the shale project in Denmark where the application of the fracking technology was permitted. Around 40 million EUR were invested into this project. However, the shale play surveys had shown that there were no reserves required for launching the commercial-scale production.

3 First Results of Shale Gas Production in Bulgaria

In June 2011 Chevron, one of the US major petroleum and gas companies, obtained the permit to development of the shale play in the northeast of Bulgaria nearby Novi Pazar during 5 years. Chevron won the bids for shale gas prospecting and development after it offered to the Bulgarian government a bonus of 30 million EUR worth for the license. The main rival of Chevron was Canadian BNK. According to initial estimates, the shale gas reserves in Bulgaria make up to 1 tcm.

After launching the shale play development that was planned to be started not earlier than in 7 years, after completion of prospecting works, Sofia expressed hopes to alleviate its dependence on the Russian natural gas export. However, already in early 2012, the Bulgarian government banned the shale gas prospecting with application of fracking technologies due to negative environmental consequences. For the breach of this ban, a penalty of 100 million Bulgarian levs or about 65 million USD was charged. The government called off the license from Chevron. Thus, Bulgaria became the second country in the European Union after France that imposed ban on the fracking technology.

In 2012 US Secretary of State Hillary Clinton and US Special Envoy for Eurasian Energy Richard Morningstar visited Bulgaria. They tried to press on the Bulgarian authorities requiring the revision of the shale gas policy. However, Bulgaria did not agree to revise the adopted decision and, in fact, postponed for an uncertain period the implementation of the shale projects.

4 Lithuania Is Seeking to Produce Shale Gas

Lithuania is also planning to develop shale plays and these hydrocarbon resources draw attention of world’s largest gas producing companies.

Several years ago, the Lithuanian scientists had already declared about availability of shale gas plays in this country stating that the shale gas reserves made around 480 bcm with the recoverable resources of 100 bcm. The prospective shale

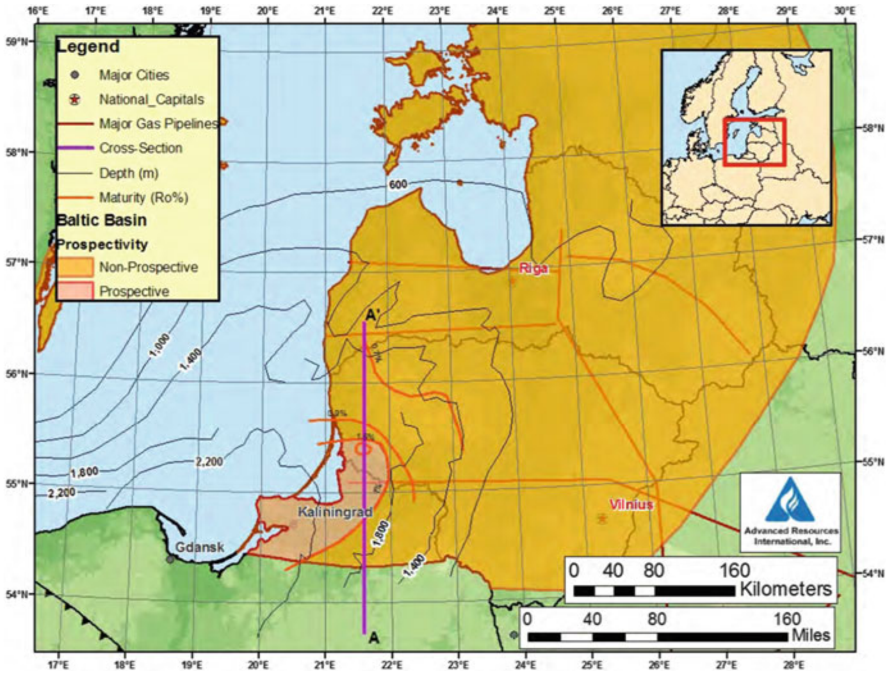

Fig. 2 Potential shale gas basins in Lithuania, Latvia, Estonia, and Kaliningrad Region (http://www.shale-gas-information-platform.org/areas/news/detail/article/lithuania-to-consider-shale-gas.html)

gas plays occur in the southwest of Lithuania and extend as far as Poland and Kaliningrad Region in Russia where they are most abundant (Fig. 2). According to rough estimates, the cost of plays may be as high as 30 billion US dollars.

In July 2011 US Secretary of State Hillary Clinton promised support of Lithuania in attaining its energy independence. The country considered the possibility to import shale gas from the USA. In November 2011 Vilnius made public its plans to conduct in 2012 the international tender for prospecting of shale plays which potential reserves, "as it was found out," would satisfy the needs of the country's economics for 30–50 years ahead [3].

However, not everybody in Lithuania supports such plans. The idea to reorientate the domestic energy sector to shale gas production evoked torrents of criticism from ecologists. The arguments voiced by the Lithuanian authorities did not convince the ecologist who firmly opposed the application of shale gas production technologies. There were many publications in Lithuania saying that because of great areas required for shale gas extraction and great environmental risks, the shale business attractiveness was rather questionable; moreover, it may incur the irreparable damage to the nature.

5 Ukraine and Belarus: First Experience of Shale Gas Production

Of all post-Soviet countries, the greatest interest to shale gas was observed in Belarus and Ukraine endeavoring to reduce their dependence on hydrocarbon supply from Russia.

Ukraine passed decisions targeted to identification of the real shale gas reserves and prospects of their development. In 2010 Ukraine initiated development of the state purposeful economic program of utilization of coalbed methane and shale gas. This program was planned for the 2010–2014 timeframe.

In 2010–2012 Ukraine was seeking to invite for shale play development such well-known Western companies as ExxonMobil, Halliburton, ConocoPhillips, and Shell. The interest to development of the rather complicated shale plays was expressed also by Eni and Total. The agreement stipulated that French Total would assess the prospects of shale gas production in Ukraine; Shell was going to organize shale gas production in the Kharkov and Donetsk regions (Yuzovsky play) with the reserves of 4 tcm and in the Lvov and Ivano-Frankovsk regions (Olessky play) with the estimated reserves of 2.98 tcm of shale gas (Fig. 3).

In 2011 Shell confirmed its interest in development of the Yuzovsky oil and gas field and its intention to invest about one billion US dollars into the shale projects in Ukraine. According to Shell estimates, the potential of the Ukrainian project was approximately 20 bcm of shale gas per year.

Ukraine cherished great hopes for the US aid with implementation of the shale projects. Accordingly, the Ukrainian government and the USA signed the Memorandum of Mutual Understanding concerning the unconventional hydrocarbon sources, including shale gas, in order to recover shale gas in the Ukrainian territory. The governments of the USA and Ukraine undertake to encourage and develop

Fig. 3 Shale gas reserves in Ukraine and Poland (http://www.globalresearch.ca/wp-content/uploads/2014/10/Shale-Gas-in-Poland-and-Ukraine.jpg)

direct contacts and cooperation among respective governmental authorities, universities, research centers, institutes, and prospecting and producing companies.

In February 2011 the company Naftogaz of Ukraine signed the Memorandum of Cooperation for prospecting the unconventional hydrocarbon reserves in the territory of Ukraine by US company ExxonMobil. It envisaged assessment of the reserves of coalbed methane, shale gas, tight gas, and other unconventional hydrocarbons in Ukraine. In September 2011 Naftogaz of Ukraine and ExxonMobil signed Draft Agreement on Unconventional Hydrocarbon Prospecting and Development in Ukraine.

In 2012–2014 the Western oil and gas companies investigated the shale plays. Simultaneously, the Ukrainian authorities conducted negotiations with the local councils in the eastern and western regions urging them to sign the Draft Product Sharing Agreement with Shell and Chevron. However, the difficulties of shale gas production, lack of accurate information about shale gas reserves, and environmental risks forced to postpone the terms of commercial-scale development of shale plays.

In 2015 the US companies continued investigation of shale plays. Regardless of finding immense shale gas reserves, the US companies refused to initiate development of these plays located in Ukraine. In late 2015 Chevron declared about unilateral withdrawal from the project on development of the Olessky play in the Lvov and Ivano-Frankovsk regions to be implemented under the Product Sharing Agreement. Such decision was taken in view of the drop of hydrocarbon prices as well as the political and economic situation in Ukraine.

In March 2015 the Dutch-British Shell closed the project on hydrocarbon survey and prospecting in the Kharkov region. Apart from the unstable political situation in Ukraine, this decision was caused by unfavorable conditions of shale gas production.

For rather a long time, Belarus did not focus attention on study of the shale plays and extraction of shale gas. The search of shale plays was considered non-perspective. However, after learning about a sharp growth of the shale gas production in the USA, the interest in Belarus to shale plays started growing, too. The works on assessing the shale gas potential were started in Belarus in 2011, and already in early 2012, the Belarusian geologists organized surveys of shale plays in the Gomel region. The Belarusian scientists admit that the shale gas reserves in their country may be significant, and in case they are found, the shale gas extraction applying the most advanced technologies is quite probable.

The priority in prospecting works was given to the Lyudvinovsky area in the Gomel Region. Some investigations of its perspectiveness were conducted, including collection of data about the fault zones in this area with which the likely occurrence of shale plays was connected.

6 Difficulties of Shale Gas Production

In 2010–2011 the European countries came out not only with optimistic declarations, but they published information about the first failures of shale gas production. Thus, in 2010 company ExxonMobil refused from implementation of the shale project in Hungary about 75 million US dollar worth as it did not find there the shale gas reserves of commercial significance.

The first results of shale play development in Europe show that no quick escalation of the shale gas production can be expected. For various reasons, it will be difficult for the European countries to repeat the US “shale revolution.”

In Europe all expectations of quick development of shale gas production were based on preliminary data about shale gas abundance and endeavors of many European countries to attain energy independence. All these factors heat up the interest to development of shale plays. However, the reality is quite different. The first results of drilling of shale plays were discouraging. The shale gas reserves fell behind expectations which made unfeasible the shale play development. Moreover, the ecological movement against shale gas production has been widening in the European countries. The opponents of shale projects point to the negative environmental impacts of application of the fracking technology and pollution of water, soil, and air. The growing public movement that pressed on the authorities urged some European countries not to hurry with the shale gas production development. The pace of shale gas production is also affected by the processes in the European gas market – the growing supply of LNG and implementation of new pipeline projects of Russian and Caspian countries. The European countries have no required equipment and technologies, which prevents them from initiating as soon as possible the shale gas production.

7 Conclusions

The pace of shale play development will depend on numerous factors and, first of all, on the resource potential of the European countries. The first results of prospecting drilling were discouraging as there were not found the shale gas resources which means development could be cost-effective. The pace of shale play development is also affected by supply of pipeline gas from Russia, slowdown of economic growth in the European countries which decreases the need in additional volumes of gas, and the deficit of the required equipment and professional personnel.

The main restricting factors for development of the shale gas production in Europe are the following: the shale plays in Europe are in their initial phase of development and have not been adequately studied in terms of geology and cost of production, intensive disturbance of the soil wholeness, and pollution of groundwaters with chemicals used in fracking, and the cost of shale development in Europe may be four times as large compared to the USA [4].

The development of shale gas production in European countries encounters powerful counteraction on the part of ecological organizations. In September 2012 the Energy Committee and the Environment Commission of the European Parliament passed the resolution concerning hydraulic fracturing of formations and development of unconventional oil and gas resources. This document stressed that the development of the shale oil and gas plays should be subject to regulation. However, this provision has not as yet found its practical application; as a result, each European country conducts the shale play prospecting and development based on its own laws.

Therefore, the shale gas may play its role in the European countries some time later when the cost of its production will be lower, the efficiency of shale play development will be higher, and the environmental risks will be reduced.

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Shale Gas Production in Germany: Ecology and Political Aspects

Oleg N. Nikiforov

Abstract The problem of the use of available reserves of shale gas in Germany is linked, above all, with the domestic gas prices and, significantly, with the security of energy supply. According to the experts of Wintershall, the leading gas supplier to the domestic market, natural gas has a crucial significance for energy supply of Germany and Europe. Company's CEO Rainer Seele said in April 2013 that the German industry was facing hard times and that it had itself created this problem (Nikiforov, Battle for gas. NG-Energia, 2013). It is connected with the rising energy prices, which is caused by the country's energy policy reform. Nevertheless, the prices are falling throughout the world both in the relative and absolute indicators. Gas prices in the USA are currently three times lower than in Germany. The Wintershall head believes that the fact that energy prices also affect competitiveness is too often neglected.

Germany's concern is caused, first of all, by the situation in the sphere of gas supply to the country's industry. Germany's energy strategy provides for a nuclear phase-out and a quick transition to renewable energy sources. This political decision was brought to the forefront after the accident at Japan's Fukushima nuclear power plant in 2011 and supported by the majority of the voting public in Germany. Gas, as the most environmentally friendly of non-renewable energy resources, should play an important role during the transitional period, that is, before the use of alternative energy sources becomes predominant.

Keywords Ecology, Germany, Policy, Shale gas

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Contents

1 Introduction

The stake on renewable energy sources and, in the context of Germany, on such sources as wind power is linked with the geographical position of the country and its energy infrastructure. Wind parks are built mainly in the north, and a considerable demand for electricity, taking the country's most industrially developed regions, exists in the south. Therefore, Germany badly needs the network infrastructure and standby capacities. And, whatever the European supporters of energy supply diversification say, to all appearances, Europe cannot do it without Russia's help. This time, not hydrocarbons, but electricity and power supply networks are meant here.

The experiment pursued by Germany, that is called "Energiewende" (energy transition), that is linked with the country's transition to green technology in the sphere of electrical power generation may fail. An initiator of the countrywide introduction of alternative energy sources in Germany, Chief Executive of DENA (the German Energy Agency) Stephan Kohler, believes that the problem is that the wind does not constantly blow and the sun shines not regularly. And these natural circumstances necessitate the construction of standby energy capacities for ensuring stable power supply for the whole country. To guarantee it, the country needs to have the same number of conventional power plants as the number of wind-driven power plants and solar panels that will be installed within the "Energiewende" programme. It should also be taken into account that this programme sets rather strict parameters of the introduction of green technology. According to them, 35% of the country's total electric power will be generated from alternative sources by 2020, and by 2050 – as much as 80%. It means that the required volume of standby capacities practically should be equal to the commissioned green energy capacities. But even the construction of conventional thermal power plants (on the condition of nuclear phase-out) is linked with considerable capital investment and long time of their construction. These circumstances considerably hinder the introduction of green technology both for Germany and the whole Europe. Kohler sees a way out of the situation in the unification of power transmission systems of Russia and Europe. The time difference between them will make it possible during the peak hours that do not coincide because of the different time zones to make large electric power transmissions from Russia to Europe and back, if necessary. The joint network operation considerably removes also the problem of standby capacities, as in this case, the corresponding Russian power plants could be used.

In the view of the German side, taking into account the existing project of solar power plants in Sahara and the 4,000-km-long power transmission lines across the Mediterranean to Europe, called Desert, then the network connection with Russia appears to be easier and more low cost from the engineering and economic viewpoints, because in this case the distance would be only 2,000 km.

This project is of benefit to Russia, to all appearances, because on the one hand, it allows it to diversify energy supplies to Europe and overcome the image of a resource-based economy. On the other hand, it will help resolve the problem of power supply to the Kaliningrad enclave by means of power exchange with EU countries. It will allow Russia to save corresponding investment that would be otherwise used to build additional capacities in the region. However, this unified grid project has a considerable political component related to Poland and especially to the Baltic states that hold to conservative stances on many issues linked with Russia.

However, these are projects of tomorrow, which require uneasy political agreements not only between Moscow and Berlin but also with Brussels. But in recent years, generating concerns in Germany have been shutting down gas-fired power plants, placing their stake on inexpensive American coal, enormous amounts of which have been released as a result of substitution of coal in the US energy balance by shale gas. Therefore, the expert stresses, Germany's energy transition is going on without gas, although it is available at low prices in the country in sufficient quantities and also (unlike coal) is neutral in terms of CO_2 emissions.

The world energy structure is currently undergoing serious changes, and the driver of this process is shale gas. It is this gas that causes price structure changes and that becomes a driving force of competitive struggle. Kohler cites data of a City Bank research, according to which, the cost of US industrial production is just 7% higher than in China, but it is already 15% lower than in Germany. It is clear that German businessmen prefer to invest not in Germany, but in the USA [1].

2 Shale Gas in Germany

It is recognised that it is Germany that has particularly large reserves of nontraditional gas in Europe (Fig. 1). Various estimates suggest that their volume is from 0.7 trillion to 2.3 trillion cubic metres. The Federal Institute for Geosciences and Natural Resources (BGR) in Hannover believes that technically recoverable volume of the reserves is 1.3 trillion cubic metres. It will be sufficient for covering the country's natural gas requirements for 13 years or (which is more feasible) for maintaining the share of domestic gas on the German market over 100 years at the level of at least the current 12%.

Wintershall is involved in shale deposit scientific research. The concession areas are located in North Rhine-Westphalia, on the border with the Netherlands. It

Fig. 1 Shale basins in Germany (http://www.science-skeptical.de/wp-content/uploads/2012/07/Geologie-Deutschland.jpg)

should be noted that the company experts already have the experience of tight gas recovery. Because shale gas is deposited in source rock pockets and, in contrast to the conventional natural gas, it cannot get itself to the land surface. In this context gas recovery from tough rock in many ways is similar to shale gas production. It is the method of induced hydraulic fracturing or hydrofracturing, commonly known as fracking, applied in Germany since 1961. The difference is that for gas recovery from tough rock, a mixture of sand and water is used. And in the case of shale gas recovery, ceramic proppant agents or aluminium oxides are used instead of sand (or along with it), in order to keep induced hydraulic fracture open for pumping out of gas. The problem is in the proppant agents. According to environmentalists, they may contaminate drinking water.

To date, the hydraulic fracturing method is banned in Germany. According to Wintershall data, starting from the middle of 2011, not a single request for the use of hydraulic fracturing, including in the conventional gas production, has been granted by the competent authorities [2]. As a result, the country's gas production in 2012 decreased by 10%. However, the company has long been using the hydraulic fracturing method in Europe, Russia and Argentina.

Germany's Federal Environment Ministry and Federal Ministry of Economics reached an agreement on the development of a joint draft law on shale gas recovery with the use of this technology. The draft law, in particular, prohibits using the hydraulic fracturing method in conservation areas and near drinking water boreholes. In addition, environmental impact assessment is necessarily made for each project. The problem is that in September 2013, Germany had parliamentary elections, and their winner – CDU/CSU (union of Germany's two main conservative parties, the Christian Democratic Union of Germany, CDU, and the Christian Social Union of Bavaria, CSU) – had to change the partner, as the Free Democratic Party (FDP) has failed to get into Bundestag. Therefore, the ministries, responsible for the economy and environment, may take tougher stances on the environment protection.

3 Priority of Ecology

As a matter of fact, according to data of a well-known German geology expert Martin Sauter from the Geoscience Centre of the University of Göttingen, there are considerable differences between Germany and the USA on the possibilities for the organisation of shale gas recovery. Therefore, Germany has more limited possibilities for shale gas production. It is caused by Germany's considerably higher population density. If the draft law is adopted, the use of the hydraulic fracturing method near zones of the sanitary protection of sources of water supply will be prohibited. In other regions it will be allowed only after a thorough analysis of the possible environmental impact. However, in recent years, the debate on the shale gas recovery methods continues in Germany [3].

It is the method of shale gas production – fracking – when a mixture of water, sand and chemical additives is injected under high pressure deep into the ground that causes concern, above all (Fig. 2). Ecologists believe that this creates the risk of groundwater contamination. Meanwhile, the President of Germany's Federal Institute for Geosciences and Natural Resources Hans-Joachim Kümpel believes that "if we start shale gas production in Germany, there will be no dense network of drilling rigs here and damage for agriculture as in the United States. We are ready to comply with the strictest norms in handling the fracking mixture. Protection of drinking water is top priority" [4].

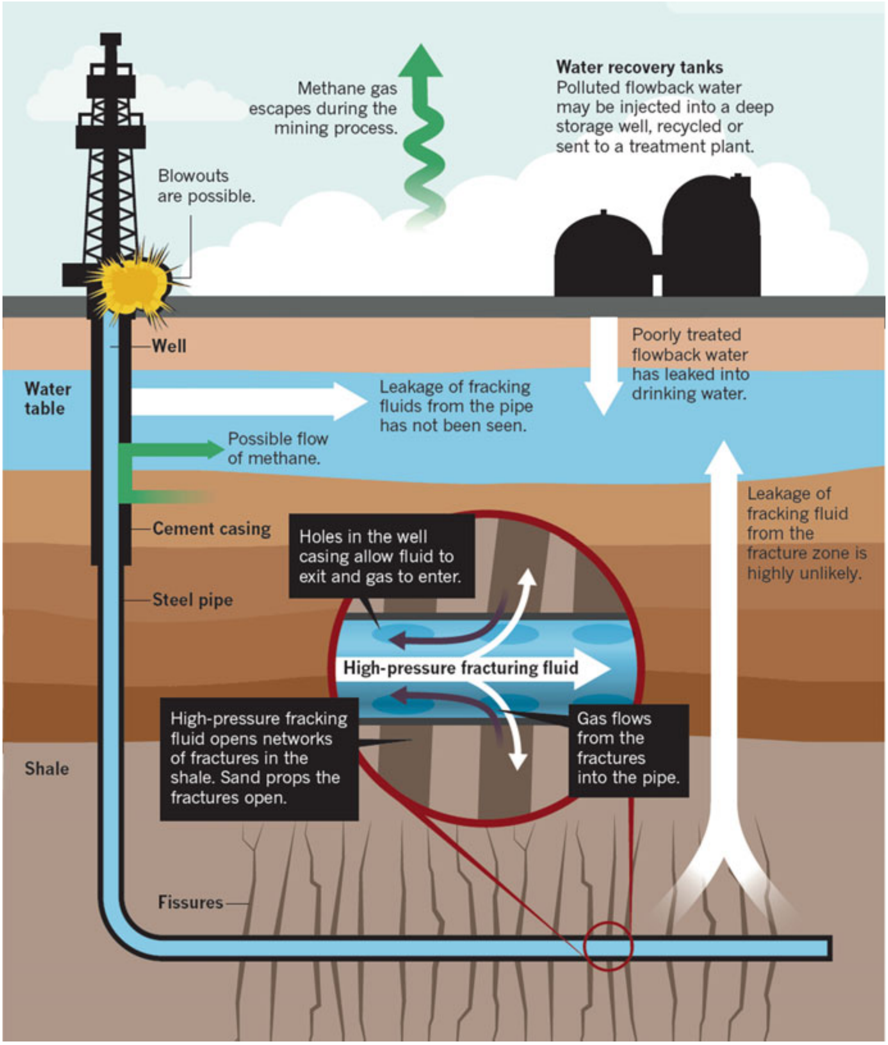

Fig. 2 Environmental consequences from the shale gas fracking (https://millicentmedia.com/2012/03/07/british-geological-surveys-shale-gas-groundwater-study-to-omit-cuadrillas-fracking-sites/)

Germany describes itself as an example to follow in the environment protection sphere. However, Dieter Helm, Professor at Oxford University, an expert in energy problems, believes that “Germany time and again speaks about climate protection and simultaneously is boosting the construction of coal-fired power plants. As Germany depends on gas, it is necessary to allow at least probe drilling in order to locate shale deposits. So long as a ban on fracking is in effect, Germany will be burning more and more coal. As a result, carbon dioxide emissions will be increasing". His opinion is shared by Esther Chrischilles, an expert at the Cologne Institute for Economic Research, who is against the unconditional ban on fracking. "The chances and risks of new technology should be carefully and responsibly assessed. But the openness to new technology improves the country's competitiveness. Therefore, advanced technology should not be rejected without reasonable grounds", the expert said. In this connection, there is no necessity for Germany to play a lone hand. Correspondingly, the question of the development of single production norms for the whole European Union now arises.

Research on the so-called water-free shale gas production is already underway. It was first mentioned in Russia in October 2013 by Professor at the Higher School of Economics Leonid Grigoriev at a seminar at the Institute of World Economy and International Relations (IMEMO), dedicated to the electric power industry's development prospects until 2040. The fundamental work says that if the test of the water-free shale gas production technology proves successful, it will be possible to speak of a "Shale breakthrough scenario" [5]. This means a gradual, relatively even expansion of the resource base, which, in the final count, is expressed in curbing the growing extraction costs, but not in the retail price collapse. The implementation of this scenario would cause an increase in shale gas production by 2040 up to 825 billion cubic metres, predominantly by means of production outside the USA. Thus, the US shale gas production volumes will reach 504 billion cubic metres; in China it will reach 164 billion cubic metres and will exceed 150 billion cubic metres in the total production volume of other countries. Shale gas recovery will be conducted in all world regions, except the Middle East. Increasing self-sufficiency of countries owing to shale gas production will be inhibiting the world gas trade volumes' growth rates. By 2040, compared to the baseline scenario, gas imports in the Asia-Pacific region will decrease by 100 billion cubic metres, and gas exports from the Commonwealth of Independent States (CIS), North America and Africa will decline.

4 Where to Recover Gas?

World gas market globalisation opens up for Germany new opportunities for shale gas production in other countries. It should be said that German companies do not plan to engage in shale gas recovery in the USA. However, Europe and South America are a different matter.

In South America, the most promising market is Argentina where Wintershall works since 1978. And on the European continent, the company intends to recover shale gas in Eastern Europe. This means for Russia that Germany's gas market will become more independent from the conventional gas supplies.

On the order of WINGAS GmbH, that is, part of Wintershall group, the European public opinion research institute TNS Emnid polled 400 energy industry experts from Germany, Austria, the Netherlands and Belgium, asking their opinion on how the European energy system would be developing in the future and which place natural gas would occupy in the energy system. The poll results confirmed that Russia, and old partner of Europe in the energy sphere, remains a key player on the European energy market and will play an important role for European energy consumers.

An overwhelming majority of German experts expect that the share of natural gas from Russia in the EU will be growing in the future, although only 52% of the polled experts called Russia a reliable supplier of natural gas to the EU. This circumstance in combination with a possible technological breakthrough in shale gas recovery determines a heightened interest in this issue.

In the meantime, Germany is placing a stake on renewable energy, which is fraught with deindustrialisation of the country. The annual conference EWI/FAZ-Energietagung in September 2013 discussed prospects for the development of the German renewable power generation, the danger of deindustrialisation of Germany, the US shale gas revolution and coal renaissance. It focused, above all, on electricity price rises in Germany, which makes the German industry uncompetitive.

Germany's business community sees the main reason for this unfavourable trend in shortcomings in the implementation of the Renewable Energy Act (in German: Erneuerbare-Energien-Gesetz, EEG) and expects the introduction of considerable amendments to it. The businessmen call for more consistent fitting of the national energy policy into the overall strategy of the European Union. Speeches of the leading representatives and experts of the German energy industry at the conference prove this conference. EU Energy Commissioner Günther Oettinger sounded the keynote for the debate. He urged the compatriots to slow down the accelerated development of renewable power generation, because its ultimate customers – both enterprises and households – have to subsidise it, which leads to the aggravation of the social and economic problems. "Already now Germany has the world's highest electricity prices, which are second only to that of Japan, Denmark and Cyprus. And in the next three years their annual growth will be 10 percent for sure", said the EU official, warning that this would only accelerate the already begun process of withdrawal from the country of especially power-consuming production facilities, referring to nonferrous metallurgy and chemical industry companies.

The head organisation of German large and medium businesses – Federation of German Industries (BDI) – is very concerned over the threat of the country's deindustrialisation. BDI Director General Markus Kerber confirmed: major companies are already exploring the possibilities for the transfer of certain production facilities from Germany to other countries, because with the current electricity prices, their competitiveness on the world market is declining. However, they are looking not to China any more, but to the USA [6]. The BDI director general compared the operation of two chemical giants: the German concern BASF and the US corporation Dow Chemical. "The manufacturing costs of their plants in Germany are by some 30 percent higher than the costs of their plants in the United States. Such difference cannot be endured for long", the BDI representative said.

The gradual deindustrialisation of Germany is unfolding against the background of dynamic reindustrialisation of the USA. The main reason for this is the US shale gas revolution, which has also caused the aggravation of the problems originated by the EEG law (Renewable Energy Act). “Germany has always sought to reduce its dependence on the imports of oil and natural gas. Accelerated development of renewable power generation, supported by all sections of society was supposed to promote the achievement of this goal and simultaneous improvement of our competitiveness”, said Markus Kerber.

All the calculations were based on the assumption that the prices of fossil fuels – oil, natural gas, coal – in the next 20–30 years would be steadily rising. In these conditions, the previous pace of the renewable power generation development no longer justifies itself. In the conditions of the existing restrictions on the production of shale gas in Germany, the chances of foreign suppliers, including Russia’s Gazprom, to increase natural gas sales in Germany will be growing.

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Shale Gas Production in Poland

Igor S. Zonn and Aleksander V. Semenov

Abstract One of the first countries in Europe that focused attention on the shale gas production is Poland that, according to preliminary estimates, possesses considerable shale gas reserves. The interest to assessing the shale gas reserves in this country has grown after commercial production of this hydrocarbon in the USA. The interest of Poland to development of shale plays was still greater if to take into consideration that this country was seeking to alleviate its dependence on the Russian gas.

Keywords Poland, Production, Reserves, Shale gas, Technologies

Contents

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1 Introduction

Poland was one of the first in Europe that has taken practical efforts to prospecting the shale plays and started developing plans of their production. The Polish authorities were forced to do this in view of the dropping level of production in the country as surveys of new fields were stopped.

In 2008–2009 Poland launched implementation of the program of investments into prospecting of its large tight gas fields. The Polish “shale revolution” supported by the US corporations was expected to increase the gas output from 5 to 10 bcm and even more [1].

The shale gas production was defined by the Polish authorities as the priority direction of the energy policy. Poland believed that the shale gas reserves in the country might be much greater than in the USA as the geological conditions here were much better compared to the US plays. This fact permitted to assume that the shale gas extraction in Poland could allow for alleviating the dependence on the Russian gas.

2 Preparation for the “Shale Revolution”

The main shale gas reserves in Poland are concentrated in three basins: Baltic with the technically recoverable resources of 3.65 tcm; Lublin, 1.25 tcm; and Podlesie, 0.4 tcm. According to EIA, the Polish “shale belt” extending across the eastern part of the country from the Baltic coast to the Ukrainian border contains around 5.3 tcm of gas [2]. However, the data of EIA experts were based on rather shallow theoretical analysis of the geological situation in different world regions, but not on the results of prospecting drilling.

According to EIA forecasts, Poland accounts for not more than a third of all shale gas reserves in Europe (17.5 tcm). Other experts assert that the shale gas reserves in Poland are as large as 12 tcm. The State Geological Institute of Poland published data stating that Ukraine possesses 5 tcm of shale gas reserves [3]. The assessments of the consulting company Wood McKenzie say that the reserves of shale gas in the northern and central regions of Poland do not exceed 1.4 tcm. Taking into consideration the annual level of gas consumption at 13–14 bcm, it was assumed that in case of shale gas development, the country will have its own gas sufficient to meet its needs for 380 years.

In 2012 the experts of the Polish Geological Institute assessed the shale gas reserves in the country at 346–768 bcm, which is much lower than the published estimates of Western analysts. They also noted that the prospecting works are progressing very slowly; still worse is the situation with construction of horizontal wells.

3 Shale Gas Reserves

Poland planned to initiate shale gas production with the help of the US companies. And the major energy corporations started purchasing land sites in Poland that became the European leader in shale gas development.

In 2009–2010 such companies as ExxonMobil, ConocoPhillips, Marathon Oil, Talisman Energy, Shell, Total, Lotos, Aurelian Oil, and Chevron purchased licenses in Poland for prospecting works on an area over 400,000 ha. Polish Oil & Gas Company (PGNiG) is also intending to join these works.

In April 2010 there was information that considerable shale gas reserves were discovered in Poland, and ConocoPhillips was planning to initiate their development. The Gdansk area on the Baltic Sea coast was meant here. It was asserted that at a depth of 2–3 km, there were found shales up to 200 m thick. Company ConocoPhillips intended to use its own equipment for shale gas extraction. Other US companies, such as US ExxonMobil and Marathon Oil as well as Canadian Talisman Energy, were intending to launch similar projects.

In 2011 British San Leon Energy during drilling of a horizontal well nearby Leben in the Pomorskie Voivodeship came across the shale gas play at a depth of 4 km. The obtained results permitted this company to announce the discovery of the shale gas reserves in the northwest of Poland. Oisin Fanning, Executive Chairman of San Leon Energy, who together with the Canadian company Talisman Energy purchased the right to development of three Polish shale plays, said that after implementation of this program, Poland would become a large gas producer [4].

The US Chevron that in July 2011 signed the service contract with the company Halliburton declared its intention to initiate prospecting drilling, especially as Poland granted the unprecedented tax privileges to Chevron.

By early 2012 the Polish Ministry of Environment issued about 90 licenses to geological prospecting and extraction of shale gas (Fig. 1).

The Polish government being in a hurry to take the leading positions in shale gas production has provided privileges to foreign companies. A company should pay 100,000 US dollars for concession and without any tenders it can obtain a permit to shale gas production. As a result of such privileges, many small companies without sufficient finance and experience in shale gas recovery came to the country.

4 Shale Gas Production

In 2011–2012 the shale projects were energetically supported by the Polish government that figured out to initiate commercial-scale production of shale gas already in 2014. The specialists of Chevron believed that the trial extraction of shale gas could start in Poland not earlier than in 2013. But many observers being very cautious in their assessments thought that the commercial-scale production of shale gas would start in 10 years at the best [5].

Fig. 1 Shale gas basins in Poland (https://www.stratfor.com/sites/default/files/styles/stratfor_full/public/main/images/Poland_920_1_0_0.jpg?itok=nmJCg55F)

But still some Polish experts believed that already by 2020, the shale gas output in the country could reach 20 bcm per year. This would not only cover the domestic needs and would permit to stop gas import accounting for 70% of the Poland requirements, but would turn Poland into gas exporter. In Warsaw such assessments were considered understated, and it was expected that by 2015 the country would produce up to 30–35 bcm of gas.

The Polish PGNiG did not share such optimism of the government. The specialists of the company believed that one could speak about any serious commercial volumes not earlier than in 10–15 years. Many experts agreed that the more accurate estimates of the shale gas reserves could be obtained only in 3–5 years and the shale gas production could have its effect on the gas balance of the country not earlier than in 9–10 years. Until that time the main source of natural gas would be Russia.

But regardless of the cautious forecasts, Poland already by 2015 was planning to get rid of dependence on the Russian gas and not only satisfy completely the domestic needs but become a gas exporter. By the commercial-scale recovery of shale gas, the Polish authorities intended to attain complete "gas independence" within two decades [6]. Accordingly, the company possessing 15 concessions for shale gas extraction in Poland figured to start experimental exploitation of Lubocino play in 2012. This permitted the Polish authorities to make forecasts according to which the shale gas production in Poland could result in Russian Gazprom loosing annually 10 bcm of gas export. The losses of Gazprom were assessed at 3–3.5 billion US dollars. Keeping in mind the plans to initiate shale gas production in Ukraine, Lithuania, and Belarus, the Russian company could lose a considerable portion of the gas market and, consequently, a sizable part of its export revenues.

5 First Results

Energetic activities of foreign companies on shale gas production development in Poland have brought first results. However, they were not so encouraging as Poland expected.

By mid-2011 there were drilled five exploratory wells. According to Petrolinvest estimates, the companies having licenses to exploration were paid around $3 billion only for trial drilling (Fig. 2).

In September 2011 the company Aurelian Oil published the first results of well drilling. They were not as bright as it was expected. The gas output was much lower than it was forecasted, while the water consumption was much greater. Two months later, in November, the company stressed that 300 wells should be drilled to make accurate forecasts. And it was also said that 20,000–30,000 wells should be drilled to exploit the full gas volume to be extracted in the Polish territory [7]. All this required the construction of the appropriate infrastructure (supply pipelines, power generation facilities, chemical plants) which would demand investing many billion dollars.

Fig. 2 Shale gas rig in Lebien, in northern Poland, where Lane Energy Poland company does test drilling (http://www.mlive.com/business/mid-michigan/index.ssf/2011/06/is_growing_shale_gas_revolutio.html)

In late 2011 British company 3Legs Resources that had been already operating in Poland drilled its first well. The company extracted shale gas, but it was not ready to say whether the Leben well in the Pomorskie Voivodeship would be cost effective [8].

The drilling results of ExxonMobil followed the discouraging results obtained by 3Legs Resources and BNK Petroleum in 2011 in Poland that for 2 years of drilling in the northwest of Poland managed to recover only small volumes of gas.

In early February 2012, it was announced that ExxonMobil drilled two experimental wells in Poland; however, they were not cost effective as the amount of the recovered gas was not sufficient to offset the cost of production. In mid-2012 ExxonMobil stopped prospecting works and refused to extract shale gas in Poland. The main reason here was insufficient volumes of shale gas for their sale which made further development of this play unprofitable.

Thus, by mid-2012 companies ExxonMobil, Marathon Oil, and Talisman withdrew from some shale projects and decided not to continue shale gas production in Poland having considered the wells not cost effective. These failures proved that the shale gas production in Poland could face difficulties, leading to gas cost growth and postponement of commercial-scale production.

Companies Chevron and ConocoPhillips started drilling test wells in Poland in order to confirm the conclusions of geologists on availability in this country of shale gas reserves. It was expected that at a depth of 3–4 km, the not easily accessible shales contained sufficient gas resources to satisfy the needs of Poland for many years ahead. Accordingly, the deeper drilling required greater investments. According to rough estimates, the cost of drilling of one well on the Baltic coast of Poland may be as high as five million US dollars, and the cost of one well in the south of the country will be ten million US dollars. Thus, the shale gas cost may reach 300–350 US dollars per 1 cubic meter.

In mid-2013 the US company ConocoPhillips managed to achieve stable shale gas recovery although its volumes have not reached the commercial scale. To keep up interest of foreign companies to shale gas production, the Polish authorities in 2014 considered different options of providing tax privileges. However, the creation of attractive conditions for foreign companies busy in shale gas prospecting has not been effective.

In January 2015 the US Chevron refused from shale gas production in Poland due to its low competitiveness. Among the reasons of abandoning by foreign oil and gas companies of shale gas prospecting in Poland, there were low cost effectiveness, technical difficulties, and too confused environmental legislation [9].

6 Conclusions

In 2013–2015 Poland failed to make a breakthrough in shale gas production although this was the critical issue for ensuring energy security of this country. Poland, like many other European countries, encountered high cost of shale hydrocarbon extraction due to complicated geographical conditions in its territory; as a result, the cost of shale projects in Europe is much higher than in the USA, which does not permit to expect in the next decade the appearance of additional shale gas volumes.

The implementation of the shale gas projects in Poland faces many problems, the key ones being the high cost of geological prospecting and production works in the initial phase of shale play development, inadequate knowledge about shale plays, and also lack of technologies. In the USA the average cost of one well is around US $ four million. In Poland the shale gas production may be possible provided the newest US equipment is applied. In addition, it is necessary to create the pipeline infrastructure to connect the shale gas plays with the pipeline system. According to estimates of Polish experts, for attainment of the shale gas production level of about 6 bcm per annum by 2025, it will be required to invest US$ 11 billion and further on to spend up to US$ 1.5 billion for increasing the gas production by 2035. As of today, the Polish government and the Polish companies are unable to appropriate such finance [3].

The interest to the shale gas production in Poland is dropping as there are no encouraging results of prospecting drilling. Nearly 70 wells were drilled and hydraulic fracturing was made in ten of them. Around one billion US dollars were invested in total. However, these wells were unfit for commercial exploitation. Some 3 billion US dollars more are required for drilling at minimum 200 more wells [10].

More conservative forecasts were made in Poland claiming to be the leader in the shale gas production in Europe. The attainment of the commercial level of gas extraction in the amount of 3–5 bcm per year is possible by 2024, which will require no less than US$ 10 billion of investments.

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Study of Some Potential Environmental Impacts of Hydraulic Fracturing Related to Unconventional Hydrocarbons in Hungary

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Abstract Recoverable amount of the already discovered and even prospective unconventional hydrocarbons in Hungary supposedly exceeds 1,500 million tons of oil equivalent, but according to modest estimates, the 30-year perspective of the recoverable amount can reach only 100 million tons by current available technology. The unconventional hydrocarbon extraction is mostly the production of tight gas, but there is a great chance of unconventional shale gas and shale oil exploration and extraction as well. Nevertheless, in Hungary the hydraulic fracturing is a precondition for the exploitation of unconventional hydrocarbon resources.

The environmental consideration of hydraulic fracturing is contradictory; therefore, its regulation and official licensing are sources of conflicts not only in Hungary but all over in Europe. We show a case study of successfully fractured tight sand exploitation in Derecske Trough (E Hungary) in order to emphasise the importance of the analyses of local circumstances and the regulatory steps determined based on those. The study focuses on the two most significant risks specific to fracturing, namely, the effect of hydraulic fracturing on groundwater and the risk of induced earthquake based on a 3D geological model of the area interpreting the real geological conditions. The main conclusions are that (1) the spatial extension of induced fractures is extremely small in the prevailing continuously subsiding geodynamic conditions; and (2) it is almost excluded that a fracturing operation would release so much energy that would cause the development of a new, significant permeable fault (or the reactivation of an existing one). (3) There is at least 2,000 m mostly impermeable and ductile sedimentary succession between the uppermost fractured zone and the bottom of the deepest thermal aquifer. It concludes that (4) the risk of a possible pollution spreading along the communication between formations does not exist and (5) the dissipation capability of young

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sedimentary formations is able to absorb the energy released by induced seismicity, which in case of the most disadvantageous technical and tectonic circumstances can trigger most likely earthquakes with a magnitude of ~1.8 in Hungary. Such an activity practically cannot be perceived by humans on the surface.

Keywords Environmental impact, Hydraulic fracturing, Pannonian Basin, Seismic monitoring, Underground water

Contents

1 Introduction

Hungary covers more than 60% of its primary energy demand by import. The import rate of petroleum and natural gas is even higher, more than 80% today that comes almost entirely from Russia. Additionally, the import through Ukraine is burdened with risk. The unilateral dependence is particularly significant in the case of natural gas. The decrease in domestic production is offset by household consumption decline in recent years (natural gas: 7.5 billion m^3 in 2013) and a benefit from the substantial natural gas storage capacity of 6.2 billion m^3.

To decrease the energy dependence and foster domestic production, the unconventional exploration potential is a considerable business in Hungary. For that it is a prerequisite to improve and make cost-effective mining technology solutions and to optimise the regulatory and social (environmental, licensing, etc.) environment, of which the regulation of hydraulic fracturing is a crucial part.

In Hungary as well as in Europe the environmental consideration of hydraulic fracturing is contradictory; therefore, its regulation and official licensing are potential sources of conflicts in many countries. Environmental authorities usually form an opinion of the particular environmental impacts (mainly the risk of earthquakes triggered by fracturing and the potential pollution of groundwater) based on international examples, although some of these (e.g. [1]) draw attention to the importance of the analyses of local circumstances and the regulatory steps determined based on those. The majority of the cited international examples are not comparable with the Hungarian conditions either, considering their geological circumstances and technical levels of operation; therefore, the consequences of those analyses should not be considered. For instance, the most often cited American shale gas deposits are associated by Palaeozoic rocks at a depth of 1,500–2,500 m, usually in uplifting geological settings, being exploited in huge fields consisting of several thousands of wells [2]. At the same time Hungarian shale and tight gas deposits are situated at depths greater than 3,500–4,000 m, in young (Tertiary) sedimentary basins of subsiding characters, where the fields would be explored by fracturing of only a few wells for the time being. Inaccurate interpretation of international examples, information taken out of their original context, can be therefore misleading and unfortunately often impose incorrect reflections in the public.

The Act No. XLVIII. of 1993 on Mining (Mining Act) in Hungary has specific regulations on enhanced oil and gas recovery, and it was among the first ones in Europe that defined unconventional hydrocarbons, well stimulation technologies, and provided a few related provisions. A recent modification in 2015 declared that the licensing of hydrocarbon exploitation operations – including especially hydraulic fracturing and acidising, the injection of water and gas – falls within the competence of the mining inspectorate. The main goal of this addendum was to highlight that the licensing of such technologies requires specific skills available at the mining inspectorate. This was necessary because recent practical experiences showed that the competence of the environmental-, water management- and mining authorities is not unambiguously separated in this respect (whether the scope of the Governmental Decree No. 219/2004 on groundwater protection covers hydrocarbon reservoirs as geological formations, or not). This has led to legal interpretation problems, disputes and controversial categorical official bans on several occasions.

Due to the licensing problems of hydraulic fracturing in Hungary, a dialogue started among the relevant ministries [Ministry of National Development (NFM), Ministry of Agriculture (FM) and Ministry of Interior (BM)], as well as the Hungarian Office for Mining and Geology involving the operators concerned. It was agreed that it is of utmost importance to analyse the environmental impacts of hydraulic fracturing and their potential realistic risks based on Hungarian case studies, considering the geological conditions of the Pannonian Basin.

As Hungary is dedicated to maximise the exploration and production of unconventional hydrocarbons – while ensuring that the public health, climate and environment are safeguarded, resources are used efficiently and the public is informed – the Hungarian Government takes into account the Commission Recommendation of 22 January 2014 on minimum principles for the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing (2014/70/EU).

The aim of this paper is twofolded. First, it provides a concise summary on Hungary's unconventional hydrocarbon resources. Then it summarises some relevant conclusions of a study compiled by the experts of the Geological and Geophysical Institute of Hungary (MFGI) [3] examining the potential environmental impacts of hydraulic fracturing in Hungary. In this paper, we present results for the Derecske Trough, where MOL Plc. has carried out unconventional hydrocarbon exploration, which also provided data on its operations especially results of their first hydraulic fracturing activities. As MOL Plc. has a mining plot for the Derecske area, the Hungarian regulation systems (103/2011(VII.4) Gov. Reg.) required the preparation of a complex sensibility and vulnerability assessment study prior to concessional activities. This study [4] analysed in great details all relevant environmental and water management issues related to future exploration and production. All of these data and information were added to the unique, national geological, geophysical and hydrological spatial database of the Geological and Geophysical Institute of Hungary (MFGI), and their re-evaluation allowed an integrated interpretation in which the effective factors, processes and interactions in space and time can be demonstrated and judged realistically.

2 Geological Setting and Petroleum Systems of Hungary with Special Respect to Unconventionals

The territory of Hungary covers the largest central part of the Pannonian Basin, which is an extensional Neogene Basin within the Alps–Carpathians–Dinaric system (Fig. 1), experiencing a very complex evolutionary history in the convergence zone between Europe and Africa, summarised recently by Horváth et al. [6].

Basin development started at the beginning of the Miocene by extensional disintegration of orogenic terranes and subsequent events of basin inversion. These deformations resulted in variable basin morphology characterised by deep

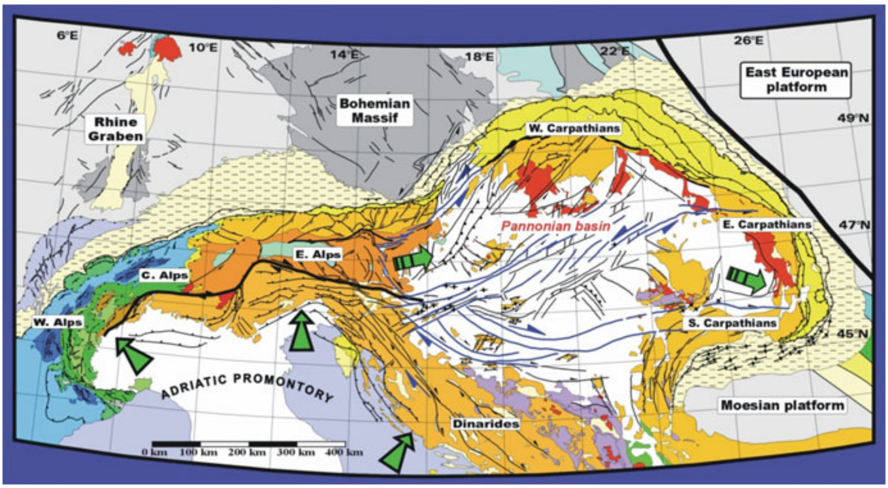


Fig. 1 Megatectonic setting of the Pannonian Basin [5]

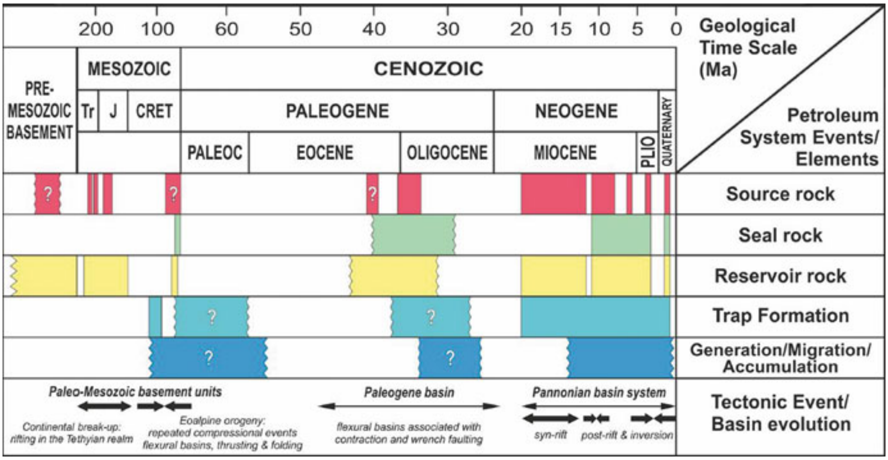


Fig. 2 Petroleum systems and events of the Pannonian Basin [9]

half-grabens, relative basement highs and island mountains exposing the substrata of the basin. The several thousand m thick basin fill can be divided into two megasequences by the base Pannonian (early Late Miocene) unconformity. In the central part of the basin (territory of Hungary), a relatively thin synrift sedimentary complex is overlain by thick post-rift strata, which were deposited by large prograding delta systems of rivers originating in the surrounding uplifting Alpine and Carpathian mountain belts [7, 8]. A Mio/Pliocene unconformity can be recognised in the basin, and its position indicates thousand metre scale differential movements during the Pliocene–Quaternary.

The different reservoir and source rocks, generation, migration and accumulation as well as different styles of trap formation can be linked to each evolutionary stage of the basin formation (Fig. 2).

Considering hydrocarbon exploration and production in Hungary, four geographical regions can be distinguished with some smaller units: (1) the Great Hungarian Plain (including Kiskunság, Szeged Basin, Battonya High, Nagykunság, Hajdúság, Nyírség and Jászság; for unconventional aspects the Makó Trough, Békés Basin and Derecske Trough), (2) the Zala and the Dráva Basin area (Zala Basin, Somogy, Dráva Basin) (3) the Hungarian Palaeogene Basin and (4) the Danube Basin (Little Hungarian Plain) (Fig. 3).

The Great Hungarian Plain is the most prolific oil- and gas-producing area of Hungary, where the country's largest but mostly depleted conventional hydrocarbon field Algyő can be found. This area is currently the main target of research of the unconventional hydrocarbons (Figs. 4 and 5). Natural gas is known in tight sandstones of the middle Miocene age in the Kiskunság area, Békés Basin area and Derecske Trough area. Gas and condensate in Upper Miocene marls and tight sandstones were drilled in the Makó Trough. The Zala–Dráva Basin in the southwestern Transdanubia region of Hungary is a conventional oil and natural gas

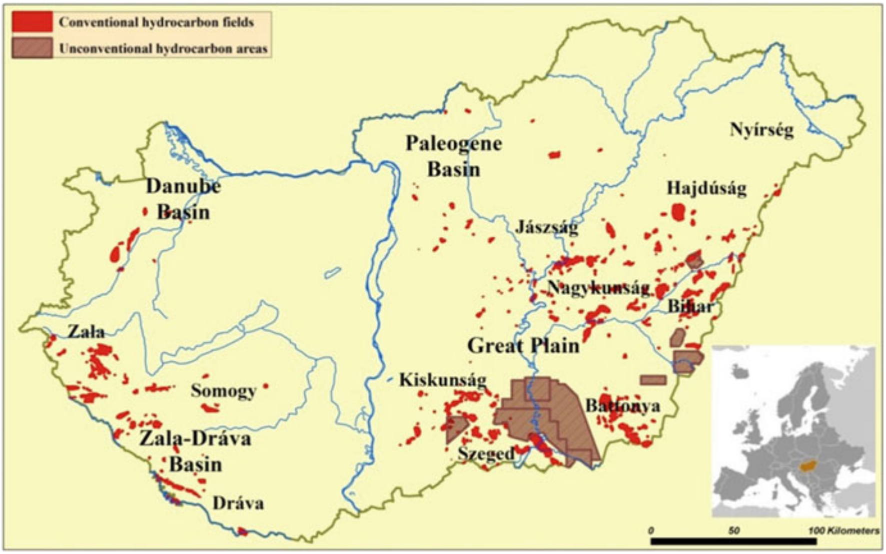


Fig. 3 Hydrocarbon fields in Hungary

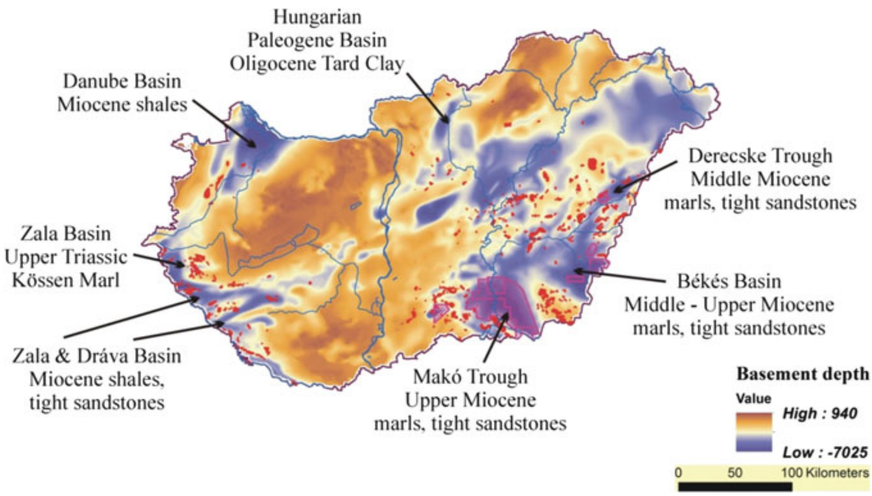


Fig. 4 Basins with discovered and prospective unconventional hydrocarbon resources in Hungary

exploration and production area that can be a perspective field of research related to the Triassic Kössen Marl unconventional shale oil and to the thick middle Miocene sandstones (tight gas) in the future. In the northwest part of the country, in the Danube Basin, mostly carbon dioxide gas occurrences are known; exploration of unconventionals has not started yet. Oil and gas fields are known in the Hungarian

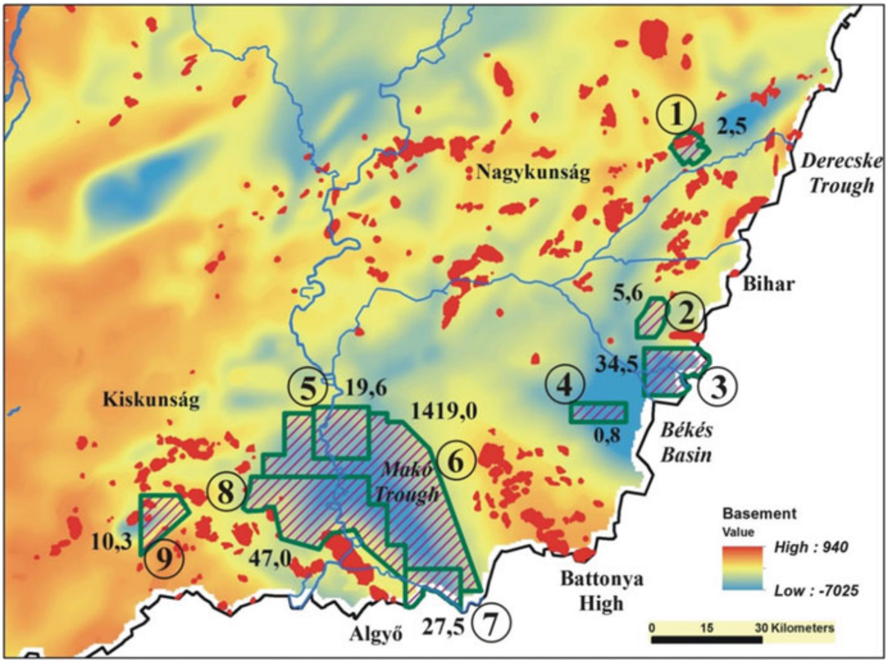


Fig. 5 Discovered recoverable natural gas resource quantities of unconventional hydrocarbon fields (mining plots) registered in the south-east of Great Hungarian Plain (billion m^3). (*1*) Derecske Trough – Berettyóújfalu, Beru wells. (*2*) Békés Basin – Nyékpuszta. (*3*) Békés Basin – Gyulavári. (*4*) Békés Basin – Szabadkígyós. (*5*) Makó Trough (north) – Mindszent. (*6*) Makó Trough – Mako Trough I. (*7*) Makó Trough (south) – Makó. (*8*) Makó Trough (west) – Hódmezővásárhely. (*9*) Kiskunság – Balotaszállás Deep

Palaeogene Basin, and shale oil exploration would be prognostic related to marls and shales of Oligocene age (Fig. 4).

As a curiosity, alginite (oil shale) occurrences are found in the inner basins of the Transdanubian Mountains that may be taken into account as unconventional hydrocarbon resources. Jurassic black coal in the Mecsek Mountains in the southern part of Hungary is counted as unconventional coal bed methane, as huge quantity of methane adsorbed on the surface of coal particles.

According to reports of mining companies, the explored in place resource of unconventional gas quantities cumulatively exceeds 3,900 million m^3. Estimates of the producibility also done by the companies suggest that more than 1,500 million m^3 can be extracted from the initial in place (Table 1). These numbers are huge compared to the current 2–2.5 billion m^3 yearly domestic production of conventional gas [10]. Furthermore, these estimates did not consider the current technology available, market prices, business opportunities and other conditions that may impede production of the large unconventional resources, including the economic yield.

Table 1 Total hydrocarbon resources on 1 January 2015 status held by the Hungarian Office for Mining and Geology

	Conventional hydrocarbon quantities	Unconventional hydrocarbon quantities
Total crude oil initially in place (million tons)	332.3	419.0
Total natural gas initially in place (billion m^3)	416.6	3,926.4
Estimated recoverable crude oil initially in place (million tons)	121.4	45.6
Estimated recoverable natural gas initially in place (billion m^3)	307.1	1,566.18
Total crude oil production (million tons)	99.9	0.0001
Total natural gas production (billion m^3)	234.2	0.0288
Recoverable crude oil (million tons)	21.5	45.6
Recoverable natural gas (billion m^3)	73.0	1,566.15

There are nine licensed assets for unconventional hydrocarbon exploration and production in the Mineral Resource Register led by the Hungarian Office for Mining and Geology, and most of them are situated in the south-eastern part of the Great Hungarian Plain (Fig. 5). During trial production in these areas, the presence of unconventional natural gas was already proved.

Hungary has 80 years of tradition in the production of hydrocarbons. In order to counterbalance the trend of the decreasing conventional reserves, foreign and domestic oil and gas companies have paid attention to the exploration and production of unconventional hydrocarbons, predominantly tight gas and shale gas during the last decade. Until now Hungary has experienced moderate success regarding the exploitation of unconventional hydrocarbon reserves; therefore, the government decided to support this sector by means of smart regulation in order to enhance the production. By the amendment of mining law in May 2015, the royalty of hydrocarbons from nonconventional sources, applying specific extraction procedures, was defined in 2% in contrast to the former 12% that refers to conventional oil and gas.

Concerning the technology of hydraulic fracturing that is needed for the production of unconventional hydrocarbons, Hungary has great experience gained along conventional hydrocarbon harnessing. The first attempts of hydraulic fracturing in Hungary are dated back to 1957. There have been more than 2,000 cases where hydraulic fracturing was applied in conventional fields for well stimulation. The modern trials – targeting at shale gas and tight gas – started in 2006. The efforts were more successful for the tight gas accumulations occurring at 3,500–4,500 m depth in Upper Miocene deposits. The economic extraction of tight gas reserves occurring at greater depth (4,500–6,000 m) in the same sedimentary sequence faces technical difficulties at present.

Almost 40 wells have been drilled for unconventional hydrocarbons on nine licensed areas, of which eight wells were tested by fracking. The atmospheric and water emissions and the noise burden were below the national and the community regulatory limits in case of these wells. No man-induced earthquakes were detected. The tests were performed in vertical wells, where inert proppants were used. In most cases, clean water was used as fracking fluid.

3 Environmental Impacts Studied

Extensive international literature discusses the environmental impacts of hydraulic fracturing [e.g. 1, 11–13]. This study deals in details with two impacts of unconventional hydrocarbon production which are debated often and pose the most significant potential risks to the environment, i.e. the effect of hydraulic fracturing on groundwater resources (by potential spread of the fracking fluid between geological formations, along natural or induced faults) and the risk of induced earthquakes. Other aspects such as impacts of the numerous wells on landscape, contamination risks associated with inadequate transport and storage of recovered fracking fluids on the surface, gas emissions to the atmosphere and potential contamination of groundwater due to poor well design and failure are not discussed.

4 The Derecske Trough Pilot Area

4.1 Geology

The recent plain surface of the Derecske Trough in East Hungary (Fig. 6) is a result of the basin evolution that started in the Early/Middle Miocene [15]; thus, 3,000–5,000 m thick sediments cover the Pre-Cenozoic basement complex. The basement that made up of mostly Variscan metamorphic crystalline rocks (mica schists, gneiss and locally amphibolite intercalation) with a narrow Mesozoic carbonate zone on the north belongs to the middle nappe of Tisza Mega-unit (Tisia Terrane) [16]. The depth of the basement is highly varying from 1,000 to 6,000 m, and it reaches its lowest point in the SW–NE orientated central trench region.

Miocene extension started in the Karpatian stage led to the formation of the SW–NE orientated Derecske Trough [15]. The deep basin is filled by Miocene siliciclastic (clays, silts, clay marls and sands, sandstones, sandy conglomerates) and volcaniclastic sediment (tuffites and tuffaceous sandstones) formations at least in 300–700 m thickness, which contain the unconventional hydrocarbons (tight gas) as well. The succession was divided into four sedimentary cycles, of which the second, characterised by turbidity-like deposits, involves the siliciclastic unconventional reservoirs, but these formations pinch out on the eastern edge of the trough. As the depocentre shifted to the NE, volcaniclastic sediments became more

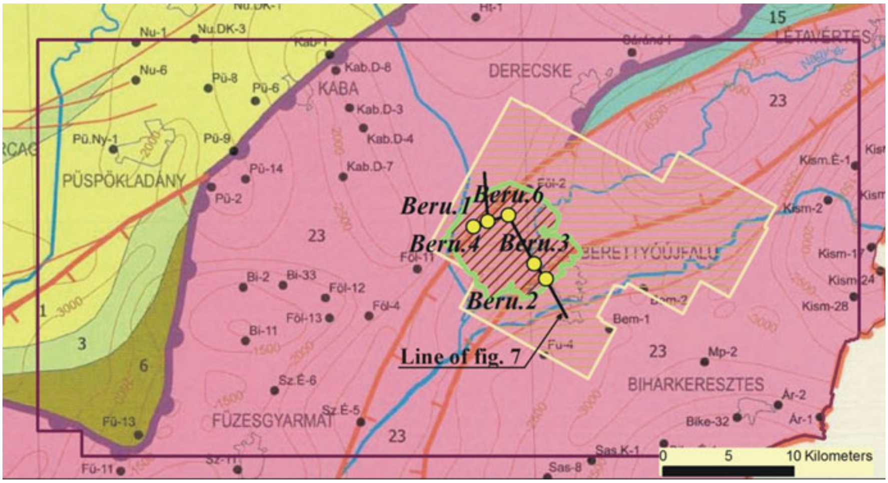


Fig. 6 The location of the Derecske pilot area: borders of Derecske concession area (*purple square*) and "Földes" 3D seismic block inside (*yellow line*), MOL's mining plot (*green line*) and Beru wells. The background is the Pre-Cenozoic basement map of Hungary [14]: (*1*) Senonian pelagic marls, flysch; (*3*) Senonian continental shallow and deep marine formations; (*6*) Lower Cretaceous platform limestone; (*15*) low-grade metamorphic Mesozoic formations; (*23*) Variscan metamorphic complex

dominant in the area. Thickness of them in the depocentre can reach the thickness of the underlying siliciclastic succession. Interbedded clay marls, sandstones and locally sandy limestones appear in the volcaniclastic sediment formations, which also contain tight gas fields. Middle Miocene clayey and tuffy beds include source rocks in several intervals and together with intercalated sands and sandstones make up a commingled system between 3,200 and 3,800 m depth.

Major subsidence and deposition occurred, nevertheless, in the post-rift phase of basin evolution characterised also by significant strike-slip tectonics [17, 18], while the Derecske Trough was also covered by the brackish Lake Pannon. The 2,500–2,800 m thick succession indicates mostly continuous infill of the trough with only one inversional event about 6.8 Ma [19]. The Upper Miocene–Pliocene (so-called Pannonian) sequence consists of the transgressional formations of Endrőd Marl and Szolnok Formations. The previous one is regarded as important source rock, while the latter, mostly turbidites, also represents remarkable potential as conventional reservoirs in the area. The continuously developing prodelta and delta slope formations (Algyő Formation) are generally clayey marls and siltstones with fine-grained sandstone intercalations. The frequently alternating sandy silty deposits of delta fronts and delta plains (Újfalu Formation), the sandy units of which are the most important regional thermal water aquifers, overlie these. The bottom of Újfalu Formation is approx. 1,300–1,400 m deep within the area. The Újfalu Formation achieves its maximum thickness (1,000–1,200 m) in the central depression of the Derecske Trough, while towards its margins, it is usually 200–300 m thick. Subsequent sandy-clayey deposits of the alluvial plain (Zagyva

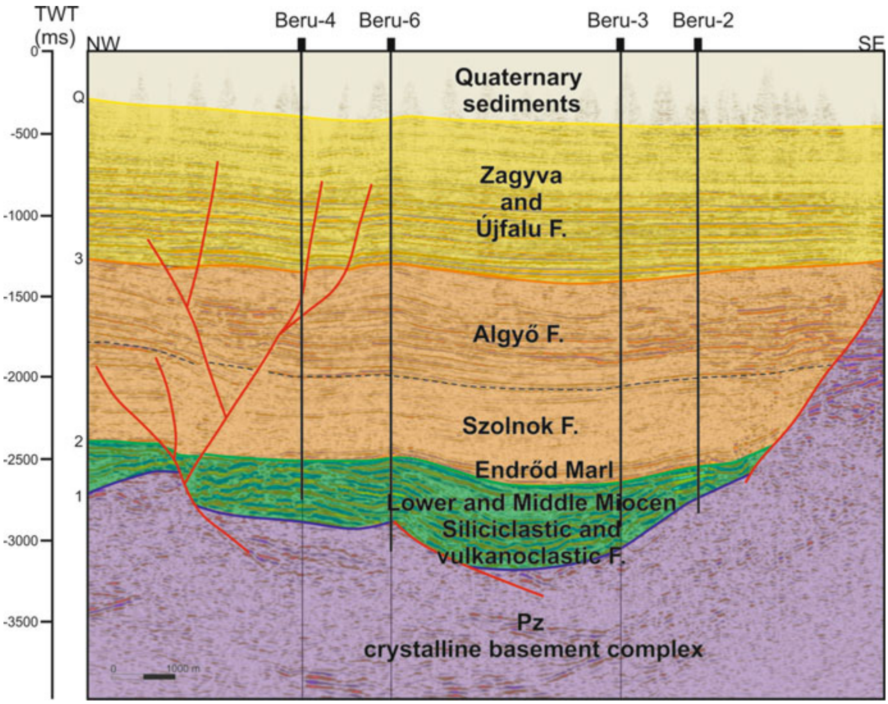


Fig. 7 NW–SE geological cross-section of the Derecske Trough. Main horizons used in 3D modelling are indicated by Arabic number. See location on Fig. 6

F.) are hardly distinctive from the underlying Újfalu Formation, and they are more than 800–900 m thick within the Derecske Trough, while in the north-western and south-eastern parts of the area, their thickness is only 100–300 m. The sedimentary succession ends with the continuous development of variegated clays of Pliocene – Quaternary lacustrine–alluvial formations in 400–500 m thickness (Fig. 7). This thick fluvial sedimentary succession representing a continuous sedimentation from the Late Miocene to the beginning of the Quaternary Period indicates a continuous subsidence of the region. Such geodynamic conditions favour the closing and clay formation of existing fractures, which is an important aspect related to the creating/ renewal of faults resulting from hydraulic fracturing.

4.2 *Hydrogeology*

The first important aquifer is situated in the Pleistocene fluvial floodplain sediments and in the underlying Pliocene lacustrine–alluvial formations. The majority of public water supply wells use the upper 100–300 m thick sandy formations of these units, which are easily accessible by relatively shallow wells, and they store water of adequate quality.

This shallow aquifer system is hydraulically connected to the underlying Upper Pannonian fluvial, floodplain, lacustrine and paludal sediments. These formations accommodate the intermediate groundwater flow system of the porous sediments of the basin.

The deepest part of the regional groundwater flow system is accommodated in the sandy units of the Upper Pannonian Újfalu Formation, which are underlain by the clayey Algyő Formation. The latter one is considered as an aquitard and therefore forms the bottom of the porous, regional flow system of the basin. Thermal waters stored in the upper part of the formation shallower than 700–800 m are $NaHCO_3$-type waters, whose approx. 1,000–3,500 mg/l total dissolved solid (TDS) content and chloride content are generally rising with the depth. $NaHCO_3Cl$-type water and 1,950–6,500 mg/l TDS content is a characteristic of aquifers lying deeper than 700–800 m.

The pressure conditions of Upper Pannonian and Quaternary formations are equal to the hydrostatic pressure.

The Lower Pannonian formations achieve their maximum thickness in the central part of the Derecske Trough, which should be highlighted because due to its aquitard nature it can significantly slow down the migration of possible pollutants deriving from the fracturing of the deeper, older Miocene formations. Waters situated deeper than 1,700–1,800 m are typically $NaHCO_3Cl$ and NaCl type. Based on the available data TDS content is mainly 5,700–10,000 mg/l; higher salinity ($>$10,000 mg/l) is characteristic of water situated deeper than 1,700–1,800 m.

The TDS content of groundwaters stored in Lower–Middle Miocene sediments varies between 10,000 and 15,000 and 24,700 mg/l with a few exceptions, and they are NaCl type.

Carbonate facies and interbeddings of Pre-Pannonian Miocene formations rank among the local porous, double-porosity systems in the study area. The waters stored in Miocene carbonate formations usually have a TDS level of 13,600–15,300 mg/l and are NaCl type or less frequently NaCaCl type implying that the aquifer is confined.

Pressure conditions in Lower Pannonian formations are hydrostatic or slight overpressure, while Miocene formations can be characterised by significant overpressure.

As the Pre-Cenozoic basement rocks are mostly fractured-karstified metamorphites and carbonates, an enhanced permeability characterises the upper several tens or possible hundred m thick zone. The waters stored in the Mesozoic formations are characterised by NaCl type and 12,200–22,200 mg/l TDS content, while waters stored in Variscan metamorphic rocks mostly contain 10,000–27,000 mg/l TDS and are $NaClHCO_3$–NaCl type. These deep aquifers are characterised by significant overpressure.

4.3 Unconventional Hydrocarbon Exploration

At the beginning of 2000s, the MOL carried out drilling exploration in Derecske–Berettyóújfalu–Földes region aiming to explore natural gas in geological structures lying deeper than 3,000 m (Fig. 7) [20]. Within the framework of this exploration programme, five wells were drilled (Fig. 6); Beru-1 and Beru-2 wells proved the in place gas resources. Beru-2 well produced 1,000–3,000 m^3/day gas influx from the basement and 500–700 m^3/day from Miocene formations. Beru-1 well tests indicated a high-pressure (57.1 MPa) and high-temperature (200°C) environment with an average porosity of 8% and an average permeability of 0.07–0.09 mD, including a good quality wet gas system. The initial test results (without formation stimulation) showed low yield and fast pressure decrease, implying the occurrence of so-called tight gas, the production of which was not economical.

Three addition wells (Beru-3, -4 and -6) were drilled to increase the gas quantities initially in place and to explore resources in deeper position. In 2011 Beru-4 well was stimulated by hydraulic fracturing. During the operation three zones were fractured between 3,450 and 3,726 m. Vertically the height of fractured zones was 60–65 m [20]. In Beru-4 well the pressure and temperature (645 bars and 209°C in 3,700 m) are also high. During hydraulic fracturing the total amount of fluid injected in three zones was 1,569 m^3, and the amount of proppant was 414 t [20].

4.4 Results of Microseismic Monitoring

The hydraulic fracturing was accompanied by successful microseismic observation and evaluation carried out partly by the Geological and Geophysical Institute of Hungary in cooperation with other subcontractors that made possible to outline the spatial position of induced fractures and the magnitude of released energy (and this way the possibly triggered seismicity risk).

The seismic monitoring system of fracturing consisted of conventional geophones (instruments used for 2D/3D seismic measurements) placed on the surface (10 Hz eigenfrequency geophone group) and a data acquisition system. During the measurement altogether 1,106 observers have been used in the approx. 4×4 km study area (in a grid of 50×300 m) (Fig. 8). As a consequence of great depth and the geological conditions (sedimentary basin), the energy of detected signals was small (its average attenuation is 10^{-10}) and it was under the background noise level (the energy of signals induced by the traffic significantly exceeded even the energy generated by the perforation of steel casing and fracturing, which was identified as highest). They could have been observed only by sensitive instruments and could not be observed by human beings at all. Since only the

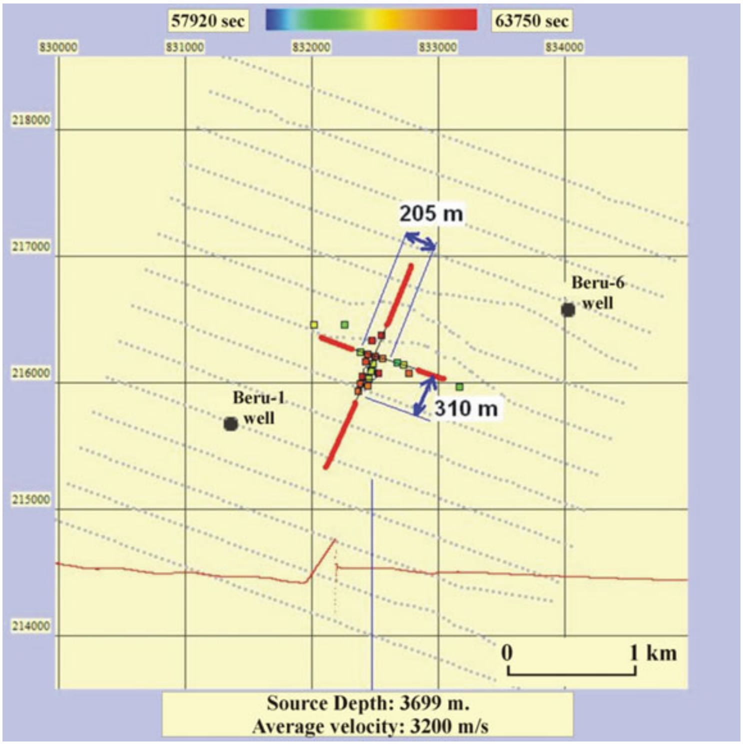


Fig. 8 The results of microseismic monitoring carried out in the neighbourhood of Beru-4 well [21]

vertical movement of the wave field has been registered on the surface by the numerous channels used during the measurements, the depth has not been determined in terms of seismology. The depth of events was considered equal to the depth of fracturing.

Figure 8 illustrates the point set of microseismic events detected during the deepest (3,700 m) fracturing. Seismic events triggered by fracturing occurred within ~300 m of the drill hole. The events can be found along two definite directions (NNE–SSW and WNW–ESE), which is in line with the main tectonic directions of 3D seismic measurement "Földes-K" determined at the same depth. The vertical size of the zone where microseismic events occurred due to fracturing is not likely to exceed the 300 m zone determined horizontally. It concludes that the zone directly affected by fracturing cannot be larger than the 300 m zone demonstrated during the microseismic monitoring, i.e. formations further than that are not influenced by the operation carried out in the drill hole.

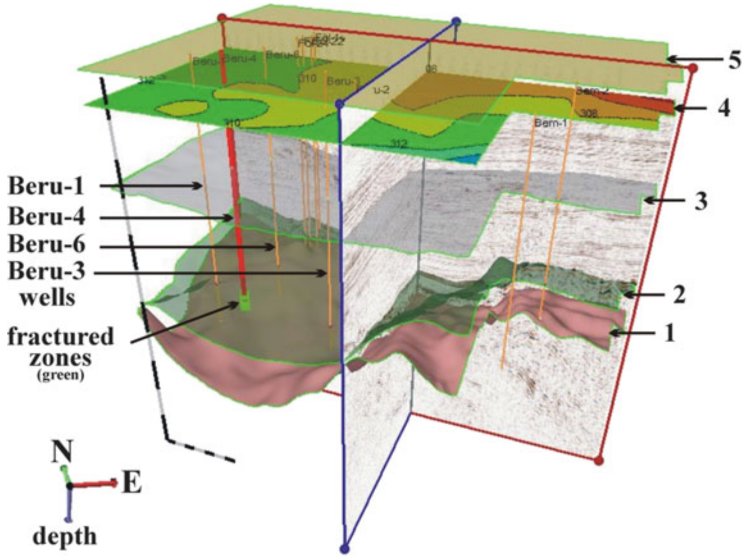


Fig. 9 The surface and the main geological levels, as well as Beru-4 well and the real spatial extension of the induced fractured zones (highlighted in *green* at the lower part of Beru-4 well) in Földes-K 3D block in Jewel software model. *Vertical* and *horizontal scale* is indicated by the scale bar where a sign means 500 m

4.5 3D Modelling of the Study Area

The analysis of the pilot area focused on the development of a voxel geological model made in JewelSuite (JewelSuite Subsurface Modelling 2014) 3D modelling software environment. Two models were elaborated: a regional model covering the whole area mostly based on existing and available geological data and subsurface maps and a more detailed model on the eastern part of the study area based on the interpretation of the Földes-K 3D seismic block (Fig. 6). Thirty-seven borehole successions were applied to the regional model and 11 boreholes to the detailed model. In order to show data in real depth, results of VSP (vertical seismic profile) measurements have been applied from five boreholes.

The interpretation focused on the 3D visualisation of key geological horizons relevant in terms of analysing the impacts of hydraulic fracturing, especially on groundwater resources; therefore, the main boundaries of the most important aquifers were also incorporated. Hungary is extremely rich in thermal waters (defined as water having an outflow temperature higher than 30°C), widely used for various purposes [22]. Furthermore 70% of drinking water resources of the country are from shallow groundwater resources; therefore, the protection of both the thermal- and the cold-water aquifers is of utmost importance.

Based on these considerations, the following horizons were built into the models (Figs. 9 and 10):

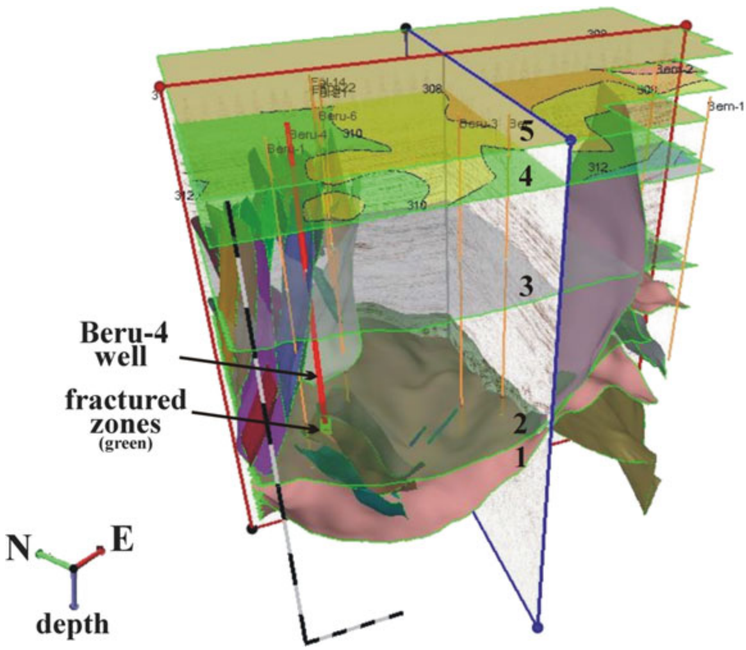


Fig. 10 Geological levels, tectonic planes, as well as Beru-4 well and the real spatial extension of fractured zones (highlighted in *green* at the lower part of Beru-4 well) in Földes-K 3D block in Jewel software model. *Vertical* and *horizontal scale* is indicated by the scale bar where a sign means 500 m

(1) The Pre-Cenozoic basin floor (top of the Palaeozoic and Mesozoic basement formations)
(2) The top layer of Lower and Middle Miocene formations (geological units that are associated with unconventional hydrocarbons)
(3) The bottom layer of the Újfalu Formation which is considered the main thermal water aquifer in Hungary
(4) The depth grid of the 30°C isotherm aiming to indicate the top of the thermal water aquifers, above which cold-water aquifers are situated
(5) The surface

The interpretation of each horizon was carried out by using 20 in-line and crossline intervals, at some parts – where the complexity of structural elements is required – along ten, five or even one line. Based on interpreted horizons, surfaces were generated by simple kriging and triangulation, which were used for making 3D Jewel grids with resolution of 500 × 500 m. Geological attributes belong to each cell of the grid model. In addition to the geological horizons, structural elements (faults) were also identified during the assessment of the seismic block as they have key importance as possible pathways in fluid migration.

5 Discussion

The spatial position of fractures developed during well stimulation of the Beru-4 well was built in the 3D model as well. Figure 9 clearly shows that the spatial extension of induced fractures is extremely small, and there is at least 2,000 m mostly impermeable (clayey Lower Pannonian and compact Miocene) sedimentary succession between the uppermost fractured zone and the bottom of the deepest thermal aquifer (bottom of the Újfalu Formation, shown by a grey layer on Figs. 9 and 10); so it concludes that the risk of a possible pollution spreading along the communication between formations does not exist.

In case of a potential pollution transport faults may also serve as conductive media, so their roles are analysed below. The faults identified based on the seismic interpretation were also built in the geological model. Figure 10 illustrates that the block is densely crossed by fault planes. However, according to both seismic interpretation and data from literature [17], the development of flower structures, which cut cross the Pannonian sediments and are related to the strike-slip movements associated with basin formation, was finished 8 million years ago in Derecske Trough; therefore, the faults cross only the several hundred, occasionally thousand m thick clayey and sandy formations (Endrőd, Szolnok, Algyő Formations).

When considering the faults' ability to conduct fluid, the material of the tectonised rock and the activity of faults have significant roles in addition to the fault geometry and the nature of stress field. The flow from the fractured Miocene formations is directly hindered by the clayey (argillaceous) components of the overlying Endrőd Marl; fractures close almost immediately after the break due to the occurrence of expansive clay minerals. The much thicker Algyő Formation, considered as an aquitard, acts similarly. The compression stress field, which is typical of the Pannonian Basin during the Pliocene and Quaternary [23], is also favourable for the closure of faults. However, it cannot be excluded that certain faults of the fault system have been periodically active recently [18, 24]. The migration along faults – at least in case of gas – is suggested by the small gas fields related to strike-slip zones explored in Upper Pannonian formations, whose source rocks are supposed to be Miocene and Lower Pannonian formations. However, it should be highlighted that these presumed hydrocarbon migrations take place in geological timescale.

If considerable amount of water flowed from the depth (e.g. along permeable faults and fractures), it would significantly modify the hydro-geochemical composition of groundwater. The chemical type of porous thermal aquifers shows that higher-salinity water may occur in Upper Pannonian formations especially in its lower part; however, it is mainly typical of basin parts where the Upper Pannonian formations lie directly on the basement or on very thin, Lower Pannonian–Miocene formations. As a consequence, higher-salinity water from deep, overpressure formations can get directly into the Upper Pannonian thermal aquifers, but it is carried out by very slow migration (measurable only on geological and not human timescale). The general hydro-geochemical diagram of the Great Hungarian Plain

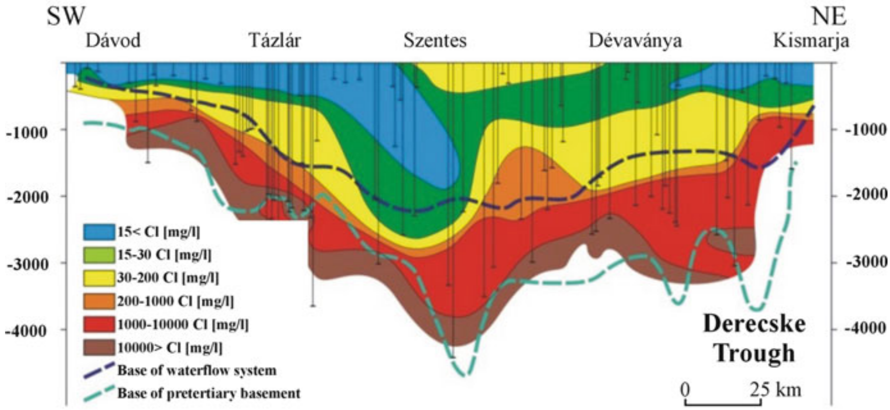


Fig. 11 Hydro-geochemical deep section in Great Hungarian Plain. The chloride ion concentration is a good indicator of deep high-salinity waters (Tóth et al. [3])

(Fig. 11) shows well separable hydro-geochemical "bedding" in line with the spatial position of the main hydrostratigraphical units; and independently of fracturing, no local mixing zones can be indicated where deep, high-salinity brines rising along a possible permeable zone would occur in less salty thermal water and which might be negatively influenced by fracturing.

The overpressure character of the deep lying aquifers also suggests that they do not have a local discharge (e.g. along an active fault plane); otherwise a significant drop in pressure would be present.

Ultimately, the question arises whether hydraulic fracturing can result in such an energy release which causes the reactivation of faults or generates new significant permeable faults. To discuss this, various aspects have to be considered:

(1) The energy of fracturing can create only a local fracture system affecting only a few hundred m zone around the well (Fig. 8), and induced microseismic activity can be detected only by highly sensitive instruments; therefore, it is almost excluded that a fracturing operation would release so much energy that would cause the development of a new, significant permeable fault (or the reactivation of an existing one).

(2) Regarding induced earthquakes, the maximal magnitude of an earthquake in a certain region is equal to the stress stored in the underground formations (that much energy can be released). Generally, the seismicity of Hungary and the Carpathian Basin is considered medium. Based on the observations so far, annually four or five earthquakes with magnitudes of 2.5–3.5 can be expected, which are perceptible but do not cause damage. Earthquakes causing moderate damage occur every 15–20 years, while stronger, more damaging earthquakes with magnitudes of 5.5–6 are triggered every 40–50 years. The distribution of quakes is not homogenous; the surrounding orogenic areas, which are the most active parts of the region in terms of seismicity, significantly differ from the

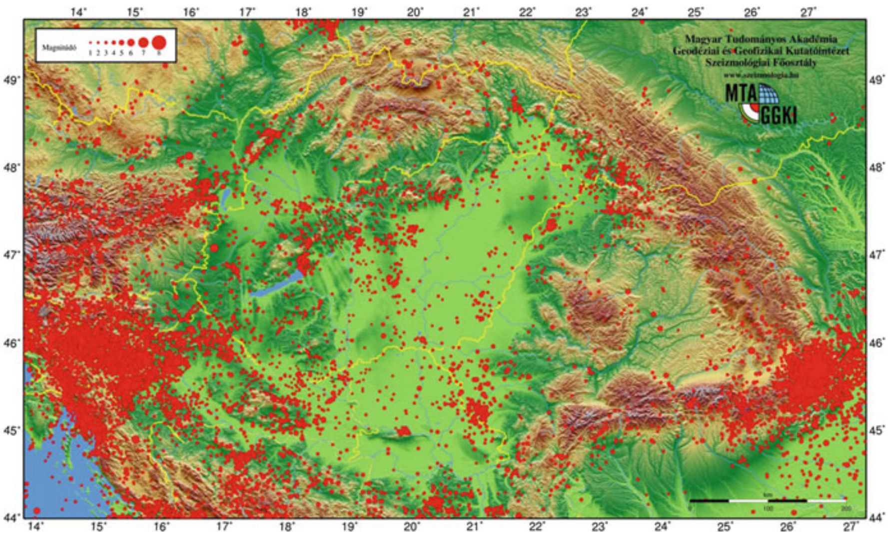


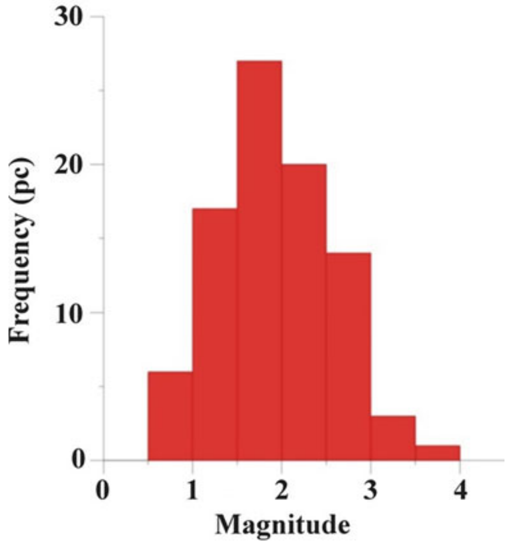
Fig. 12 The areal distribution of earthquakes occurred in the Carpathian Basin and its neighbourhood between 456 and 2006. The size of symbols is proportional to the Richter magnitude of earthquakes (1–8) (www.seismology.hu/images/cikkek/seismicity/a_karpat-medence_foldrengesei.jpg)

inner part of the basin. Areas affected by hydraulic fracturing (primarily the Great and Little Hungarian Plain) are the less active parts of Hungary (Fig. 12). If unfortunately energy is released from a tectonic zone during fracturing, the quantity of the released energy can be estimated. The statistical analysis of determined earthquakes [25] clearly points out that flexible energy accumulated in the part of the Pannonian Basin affected by hydraulic fracturing can most likely generate earthquakes with magnitudes of 1–2.5 under natural conditions (Fig. 13). Induced seismicity releases a part of the accumulated stress so in case of the most disadvantageous technical and tectonic circumstances earthquakes with a magnitude of ~1.8 can be triggered in Hungary most likely. However, the dissipation capability of young sedimentary formations able to absorb energy should also be considered, thanks to which such an activity practically cannot be perceived by humans on the surface.

(3) The development of brittle fracture is moderated in the porous and intercalated sediments (e.g. clays, silts, sandstones, etc.) characterised by lower strength, preventing energy absorbance and fault development. Growing temperature acts also against the development of brittle fractures, increasing the viscous nature of the rock and this way its energy absorbability. This effect is significant at great depths of the Pannonian Basin because of the geothermal gradient over the world average.

The upper on average 3 km (0–6 km) thick young (Neogene) sedimentary part of the Pannonian Basin is made up of low strength, porous, clayey rocks, which on the

Fig. 13 The distribution of magnitudes of earthquakes in the above 10 km of Pannonian Basin based on literary hypocentre and magnitude data determined so far



one hand can significantly diminish the energy of earthquakes and on the other hand are not favourable in terms of seismic activity. Due to the considerable amount of young sediments as well as the high geothermal gradient improving the plasticity and viscosity of deep rocks, the seismic activity in Hungary differs (positively) from the world average. In other words, because of the above-mentioned factors, the seismic activity in the Pannonian Basin is lower than in several other basins of the world.

Consequently the risk of induced seismicity and its surface impact is low due to the geological conditions of Pannonian Basin.

6 Conclusion

Hungary is dedicated to maximise the exploration and production of unconventional hydrocarbons, for which the hydraulic fracturing is a precondition by the introduced geological conditions of the Pannonian Basin. However, contradictory environmental consideration and resulting licencing problems of hydrocarbon exploitation operations – including especially well stimulations – call attention of the importance of the analyses of local circumstances and the regulatory steps determined based on those. Therefore, the experts of the Geological and Geophysical Institute of Hungary compiled a study for examining the potential environmental impacts of hydraulic fracturing in Hungary based on a 3D geological model of a relevant study area [3]. The study clearly shows that the risk of a possible pollution spreading along the communication between the fractured and aquifer formations does not exist, and it is almost excluded that a fracturing operation would release so much energy that would cause the development of a new, significant permeable fault (or the reactivation of an existing one), so the risk of induced seismicity and its surface impact is also low due to the geological conditions of Pannonian Basin.

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An Overview of Unconventional Resources of Romania. Pending Challenges

Bogdan M. Popescu and Nicolae Anastasiu

Abstract Romania has a quite large inventory of unconventional continuous plays in the Paleozoic, Mesozoic, and Cenozoic periods mainly in the foreland and back-arc basins. The assessing of units evaluated so far, following the EIA and USGS methodology is underway but first results indicate technically recoverable resources of 1,000 billion m^3 of gas and 500 million bbl of oil. They show a tangible potential for investors once a specific legal framework is in place. The geological challenges for evaluating this category of resources are rather important because of the lack of novel information resulting from modern exploration and the classification regime of older one. The political hurdles are related to incomplete regulations, absence of community co-involvement, and the lack of any policy promoting the development of unconventional resources. The environmental debate has been very present in Romania and shall hopefully be solved with an unceasing consultation with the public society once new, transparent rules are set up.

Keywords Assessment units, Basin-centered gas, Clathrates, Coal bed methane, Gas, Oil, Plays, Romania, Tight gas, Unconventional

Contents

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1 Introduction

Romania is definitely one of the European countries with a real endowment of unconventional oil and gas resources. Some of them have been known and explored much before the US "unconventionals fever" of the beginning of this century. They were produced after the WWII at Suplacu de Barcău (*tar oil sands*), in the Pannonian Basin, at Anina (*oil shales*), in the Reșița–Moldova Nouă Basin, and in the fractured gas fields (*tight gas*) from the Transylvania Basin. However, systematic studies of the country's full undiscovered potential were generated only after the unprecedented US exploration and production exploits at the turn of the century. They were materialized in first reports after 2010 that start looking at the potential of a new paradigm whereby the source rocks of conventionally trapped hydrocarbons can be continuous reservoirs of unconventional hydrocarbons, e.g., Krezsek et al. [1], Velciu and Popescu [2], and Anastasiu et al. [3]. First Romanian specific exploration efforts were initiated by Chevron, also after 2010 when it acquired the Bârlad (NE Romania) concession from Regal. A seismic 2D survey and the Siliștea 1A well were later completed followed by an application for the relinquishment of the concession in 2015; it appears this was likewise associated with the similar acreage withdrawal from Ukraine and Poland.

Albeit data used for the present evaluation are scarce and partial, authors have been consistently used for the evaluation of plays described below, the updated approach for the evaluation of technically recoverable undiscovered resources proposed by USGS (e.g., [4]) and EIA in 2011–2013. The assessed resources in this paper would be produced with current technologies, regardless of other costs. It must be emphasized though that some of the specific parameters currently used in the full evaluation of the unconventional plays are missing in Romania where exploration was carried out almost exclusively for the search of conventional hydrocarbons for more than 150 years.

If Romania eventually decides to seriously promote this kind of resources, the National Agency for Mineral Resources (NAMR) must be the spearhead of the movement. It should promptly adopt a new vision, in line with UE exploration practices, whereby at least a limited set of specific exploration and production code of practice for the unconventional resource development shall be in place. This new vision should equally include, for the first time in local practice, the release of the *to-be* declassified geological information. In addition a full access to the vintage core, geochemical and paleontological material must be unlocked for inspection and reconsideration as well as the initiation of exclusive and non-exclusive studies for unconventionals evaluation. A positive aid of the investment in the Romania unconventional resource exploration would be at best, the consent for acquisition of modern deep reflexion seismic over the main prospective and frontier areas which must be negotiated for exclusive, or allowed for non-exclusive, rights.

All these minimum requirements for a successful implementation of initial exploration programs need a clear and long-term energy strategy in addition to stable, predictable, and transparent regulations. Bringing online proved economic prospects could need billions of Euros in investments and years of hard work which means that responsible politicians must, at best, stop making confusing statements on these resources every 4 years, only during the election campaigns. This has been resulting in never ending changing policies, whilst the enforcing relevant legislation to pave the ways for such an investment had been indefinitely postponed.

Finally, all civil society stakeholders shall agree, after wide consultations, the ways to mitigate the environmental and social risks that might occur during activities related to exploration for and production of unconventional oil and gas.

2 Main Unconventional Plays

The geological framework of Romania is a dominated by the Carpathian Belt coupled to its foreland and younger back-arc basins (Fig. 1) of which, at the present, an area over 30,000 km^2 is estimated prospective for unconventional resource exploration. The information used for this evaluation of the unconventional resource potential is based on published well and seismic informations. The results of Chevron exploration for Paleozoic gas shale resources were not made public.

In Table 1 there is an inventory of the possible locations for unconventional exploration prospects sited mainly in continuous mudstone or sand plays in contrast with the well-known conventional, structural, or combined plays which are in a mature and super mature stage of exploration in Romania. Other unconventional plays were assessed in units referenced by age in country's main geological units and that could become viable economic targets after additional exploration.

2.1 Oil and Gas Shales and Sands

In Romania, the conventional source rocks and related continuous plays of unconventional oil and gas accumulations could be found in almost all Phanerozoic periods, from the Paleozoic to the Neogene (Fig. 1 and Table 1). In addition, tight gas and tar sands were partly explored and produced in the country. They are situated in the foreland or back-arc basins as well as in folded belts. The latter,

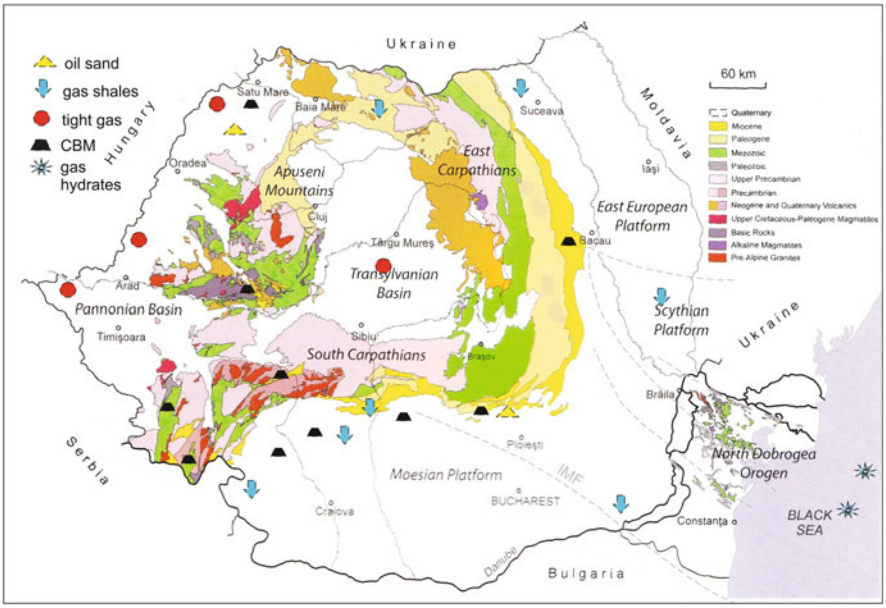

Fig. 1 Map of Romania showing main structural units and location of the unconventional resource plays (geological background from [5])

Table 1 Geological time repartition of the unconventional plays in Romania (for key to symbols see Fig. 1)

		Foldbelt Unit		Foreland Units				Tertiary Back Arc Units		
	→ Pr:	East Carp.	South Carp.	Moldav	Scythia	Moesia	Getica	Transylv	Pannon	Black Sea
Period	mil. y.									
Quaternary	1									gas hydrates
Pliocene	5	CBM				CBM			CBM	
Miocene	23	CBM	CBM					tight gas	oil sand, tight gas	
Oligocene	33	gas shales	CBM				gas shales			
Eocene	55									
Paleocene	65									
Cretaceous	145								CBM	
Jurassic	199		CBM			gas shales				
Triassic	251									
Permian	299									
Carboniferous	359		CBM							
Devonian	416									
Silurian	439			gas shales	gas shales	gas shales				
Ordovician	488									
Cambrian	542									
Ptz	2500			gas shales						

although contain excellent and active organic-rich continuous plays, are in the category of longer term resource production potential due to their overall advanced tectonism and rough terrain.

2.1.1 Paleozoic

The Paleozoic anoxic event in the Silurian basins located on the Eastern Europe Craton (Baltica) or on the Eastern and Western Moesia is interpreted as an important target for the unconventionals shale accumulations exploration. The black, graptolite shales or argillites of the Rădăuți and Țăndărei, respective formations mapped on the Moldova Slope and on the Moesian Platform (Figs. 2 and 4), are typical continuous plays [2]. While on the Moldova Slope the thick development of

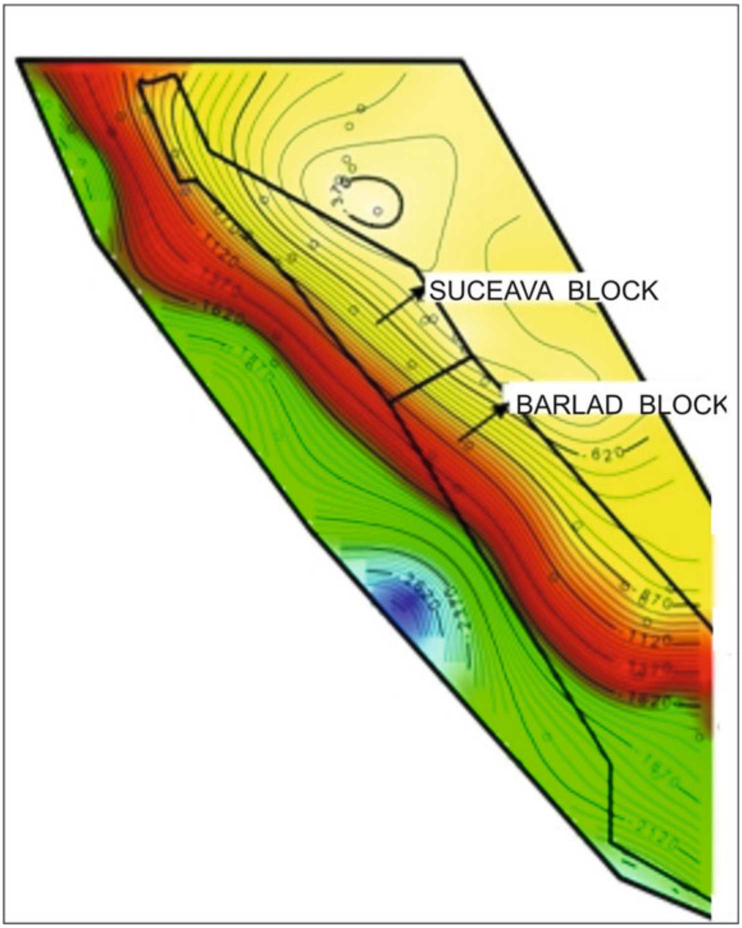

Fig. 2 General trend of top Early Devonian isobaths on the Moldova Slope and Basin (from [6])

the Rădăuți Formation appears to be restricted to Rădăuți–Roman Block [8] flexural basin slope (e.g., [9]), on the Moesian Platform, prospective Țăndărei shales are mainly located in grabens and half grabens [1].

Younger Paleozoic formations of the Moesian Platform carbonates and shales could also be a candidate for their unconventional hydrocarbon potential; however, available published data do not allow an assessment yet.

Moldova Slope and Basin

The Silurian "graptolite shale" Rădăuți Formation is grading laterally westwards from the carbonate and siliciclastic Bătrânești Formation. These Silurian facies distributions over the Baltican basement display an almost sublongitudinal facies belt developing from the Baltic Basin in the North eventually reaching the area between Prut and Moldova valleys (2, 10) at the southern end of a facies tract extension marked by the Murgoci Lineament [8]. On the western, Rădăuți–Roman Block of the Moldova Slope it consists of up to 1,400 m thick (Figs. 2 and 3) black siliceous mudstones, siltstones, and marls with thin intercalations of sandstone or carbonates and tuffs.

The Rădăuți Formation has been considered one of the main candidates for investigating the unconventional shale in Romania (Table 2). The only specific exploration was carried out by Chevron between 2010 and 2015. The results of the 2D seismic and of their Silistea 1A well are still tight, thus no explicitly focused studies about the shale gas properties of this formation are publicly available. Sparse published information show rather good parameters but those of TOC (Table 2). However, peaks of 6.6 (wt.%), originating from the Malopolska Block (probably

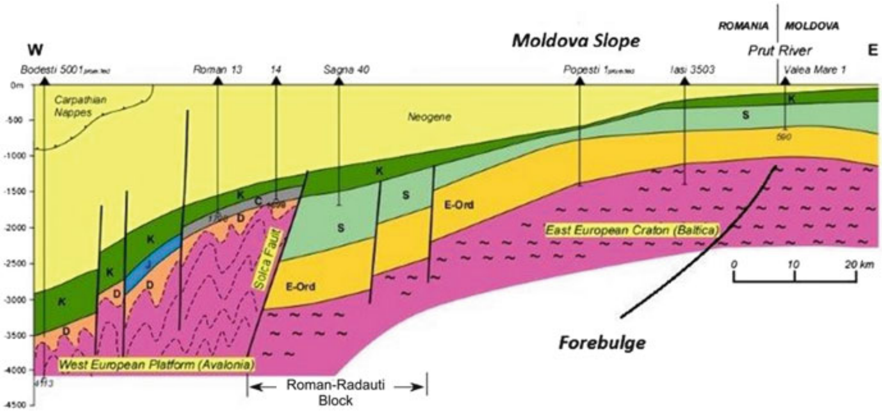

Fig. 3 Cross-section over the Moldova Slope and West Europe Platform showing the rapid thickening of the Silurian on the Rădăuți–Roman Block (from [11], modified from Paraschiv 1986)

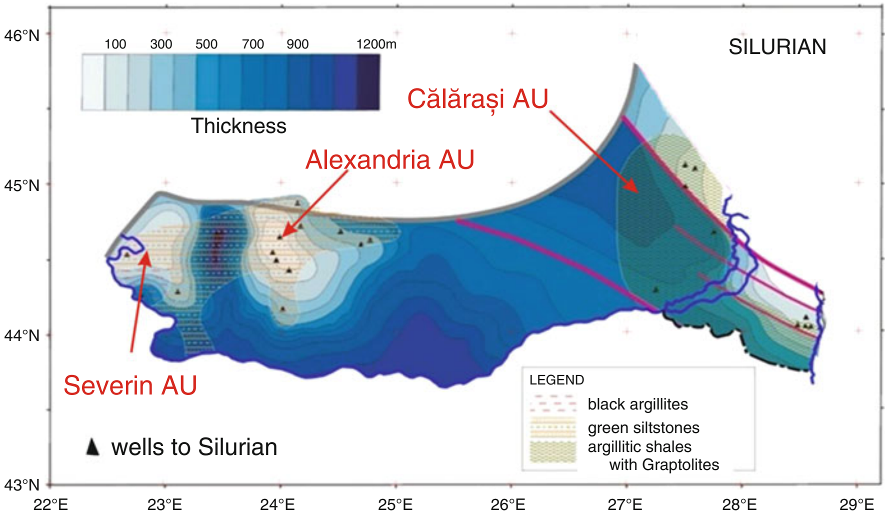

Fig. 4 Location of main assessment units and thickness of the Silurian Țăndărei Fm (modified from [7])

Table 2 Main characteristics of the Moldavian Slope and Basin Paleozoic AU (Amended from [2])

Plays		Roman–Rădăuti AU	Bârlad AU
Basic data	Shale formations *Rădăuți Fm*	Black mudstones, argillites (70–80%); silts sands, carbonates (20–30%)	Black mudstones, argillites (70–80%); silts sands, carbonates (20–30%)
	Geological age	Silurian–Lower Devonian	Silurian–Lower Devonian
	Prospective area (km^2)	7,000	1,000
Physical extent	Depth top of play (m)	1,000–2,350	900–3,800
	Avg. play thickness (m)	90	80
	Pressure (Atm)	35	30
	Temperature (°C)	107	110
Reservoir properties	C_{org} (%)	na	na
	TOC range (wt.%)	0.1–1.6	0.1–2.4
	Thermal maturity (R_o)	0.35–1.6	0.58–3.6
	T_{max} (°C)	na	na
	Kerogen type	II	II
	Volume factor Bg	0.0048	0.0033
	z-factor	0.860	0.900

located west of the Roman-Radauti Block (8)) were quoted from the Silurian of Poland [12].

The presence of high organic carbon and low TOC from wells drilled in the Rădăuți Formation in Romania and South Ukraine and in similar age source rocks of Northwest Ukraine and Poland [13, 14] raised the problem of the actual existing potential for unconventional hydrocarbons of the Silurian continuous play. The CAI of 3–5 and 1.3–3.5 R_o (%) of Silurian shales shows they would had been in the dry gas window (fide [14]) and now are overmature [13]. The Rădăuți Formation organic-rich interval lacks pyrolysis data.

The high CAI maturity of the kerogen type II from these shales indicates that during the initial, pre-thermal alteration, TOC content was much higher [13], possibly exceeding 3 (wt.%). This points out to the necessary increase of the exploration work in the Silurian plays of Romania and Ukraine for gathering better definition of the geochemical and maturation parameters.

Moesia

The Țăndărei Formation is mainly a siliceous mudstone, sedimentary unit developing in both the Eastern (Dobrogean and shallow offshore Black Sea) as well as in the Western (Wallachian and Pre-Balkan) sectors of Moesia which are separated by the crustal Intramoesian Fault. The thickness of this formation varies but the highest values were reported in the Călărași, north Alexandria, and Severin Sub-basins (Fig. 4) and assessment units.

Facies is typical graptolite shale up to 1,200 m thick, containing sparse carbonate mudstones or quartz sandstones and tuffs interbeds [7]. Although only limited a number of geochemical analyses are available, the Țăndărei Formation appears to be quite lean with the known TOC information. With no tailored exploration carried out yet, it is hard to select sweet spots at this low level of knowledge of the play and comments mentioned for the Rădăuți Formation apply to the Țăndărei one as well.

In the Severin Sub-basin, less than 1,000 km^2 was considered prospective (Table 3) in the Severin AU. It has a reasonably good thickness of organic-rich shales ([15], Transatlantic website) and burial depths to be worth exploring. The average thickness of the organic-rich interval in target areas is of few hundred meters compared with over 1,000 m the total Silurian thickness in the Eastern sector of the sub-basin.

In the Alexandria Sub-basin, the area of optimum depth development of shale gas formations is located on its northern border, close to the Balș–Optași High shoulder (Figs. 4 and 7). The characteristics of the Silurian shale reservoirs are: HC total 168–688 ppm, HC/TOC (mg/g) 20–90; Pr/Ph 1.19–1.99 characteristic of an anoxic environment [16] showing a moderate to good expulsion potential of the marine kerogen type I–II. The Țăndărei siliciclastic mudstones are here in the dry gas window at some 2–3 km depth [1].

The Călărași Sub-basin is located on the Eastern Moesia onshore and extends offshore (e.g., Delfin 1 well graptolite shale interval). The good quality graptolite shales and argillites shows an intra-Ludlow unconformity [7] and display a potentially favorable shallower areal extent east of the Capidava–Ovidiu Fault (Fig. 5).

Other Paleozoic formation of interest could be the bituminous carbonates (kerogen type II, 0.8–1.25% TOC) of the Devonian Călărași Formation believed to be

Table 3 Main characteristics of the Moesian Platform Paleozoic AU (amended from [2])

Plays		Severin AU	Alexandria AU	Călărași AU
Basic data	Shale formations: *Țăndărei Fm.*	Black shales 75%, silts, sands 25%	Black shales 70%, carbonates, sands 30%	Black shales 80%, silts, sands 20%
	Geological age	Silurian–Mid-Devonian	Late Ordovician–Mid-Devonian	Late Ordovician–Early Devonian
Physical extent	Prospective area (km^2)	600	7,000	9,000
	Depth at the top of play (m)	2,000–3,800	2,000–3,500	1,500–4,500
	Avg. thickness of the plays (m)	300	700	800
Reservoir properties	Pressure (Atm)	230	230	228
	Temperature (°C)	95	89	80
	C_{org} (%)	0.8–1.35	0.95–1.8	0.24–1.24
	TOC range (wt.%)	0.1–1.9	0.1–3.5	0.1–1.5
	Thermal maturity (% R_o)	0.7–1.9	0.85–1.4	0.4–2.5
	T_{max} (°C)	450 est	430 est	440 est
	Kerogen type	I–II	I–II	II–III
	Volume factor Bg	0.0037	0.0043	0.0049
	z-factor	0.9922	1.000	1.100

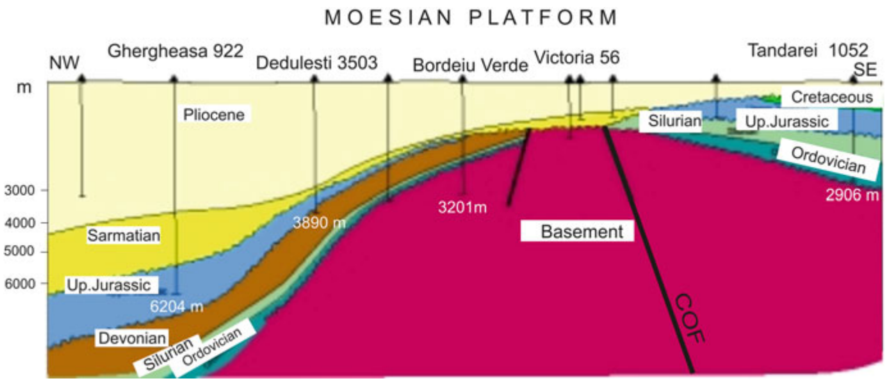

Fig. 5 Cross-section in the Călărași AU (modified from Veliciu unpublished paper)

in the gas window and probably sourcing some conventional fields in West Moesia. We do not have enough specific information allowing an assessment of their bituminous carbonates, black mudstones, and coal-measures sequences for a nonconventional hydrocarbon potential.

It is worth mentioning that older anoxic events are also known in the Ediacaran (Naslavcea Formation) of the Moldova Slope but its shale gas potential has been so far barely investigated only in the shallow portion of the basin [17] showing a rather poor expulsion potential.

2.1.2 Jurassic

The "Posidonia shales" were laid down during the continuing opening of the Tethys in the Alpine area in the late Liassic and Dogger. These organic-rich rocks were sedimented in a highstand anoxic event related to rifting that resulted in the deposition of a world-class source rock for many oil and gas fields in Europe, including in Romania.

Moesia

The Râmesti Member of the Bals Formation is the source rocks that charged hydrocarbons into some large conventional oil fields in West Moesia. These Bajocian–Early Callovian siliciclastic mudstones contain 20–30 gOM/100 g rock [18]. They may reach up to 700 m in thickness [19] in the front of the Pericarpathian line (Figs. 6 and 7).

Gheorghe et al. [16, 19] report the following parameters for the Mid-Jurassic shales: EOM: 216–2,042 ppm; HC: 50–13,396 ppm; Pr/Phi 1.16 avg, showing a

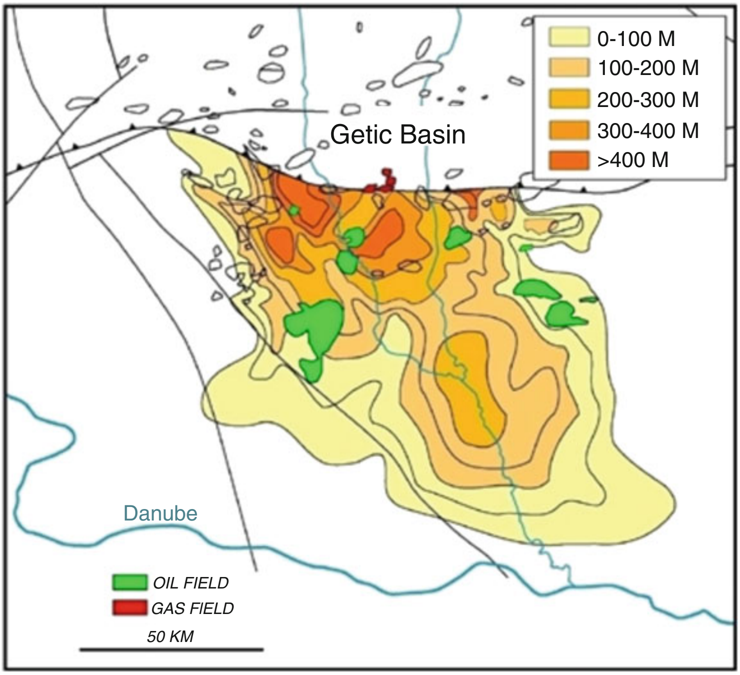

Fig. 6 Isopach map of Balş Formation containing the organic-rich Râmesti Member (from [20] adapted from [18])

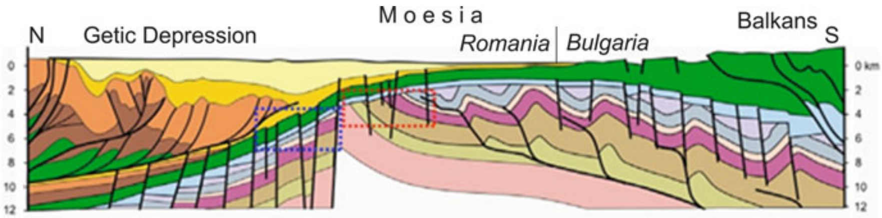

Fig. 7 Moesian Platform cross-section showing the location of the Bals and Alexandria plays (from [1])

moderate to good expulsion potential. At 4,000 m depth HI is between 120 and 210 mg TOC and PI ranges between 8 and 9.1% placing the Râmesti Mb in the oil window. Between 4,400 and 4,600 m R_o averages 0.51. The unconventional shale gas potential of the Moesia Jurassic shales was pointed out by Tari et al. [20]. TOC is of a rather good quality with some 60% of the bulk rock having values between 1 and 2% [1]. The vitrinite reflectance shows that the maturation starts at 1,800 m and 70°C and bottom at 4,500 m and 180°C [18] making the Râmesti Mb one of the deepest unconventional oil shale plays in Romania.

South of Danube, its extension, the Etropole Formation is also the source rock for a number of conventional fields in Bulgaria. The Etropole bituminous shales have been reported recently being in an advanced stage of their unconventional potential evaluation by a foreign operator.

Moldova Basin

The Bârlad "depression" is actually a sub-basin of the Moldova Basin [8]. The latter has a long and complex history starting in the Proterozoic and ending in the Neogene. The Bârlad Sub-basin develops south of the Murgoci Lineament from the Carpathian leading thrust line in the West until the Nistru crustal fault in the East. A number of conventional gas, condensate, and oil fields were sourced by the Mândrişca Formation (Fig. 8), a similar source rock comparable with the above mentioned, coeval Râmesti and Etropole formations. Eastern of the Barlad Sub-basin up the Black Sea, the equivalents of the Mândrisca Formation, e.g., Artiz and Andrus formations have not yet proven an expulsion potential.

The great thickness and the maturation status of the Mândrişca Formation, black siliciclastic mudstones, and associated silts or sands from the axial area of the Bârlad Sub-basin make it as a good candidate for the shale oil and gas exploration. The maturation occurred below 120°C at 4,000–4,500 m depth in the Homocea–Buda–Ghidigeni area (Fig. 9 and Table 4).

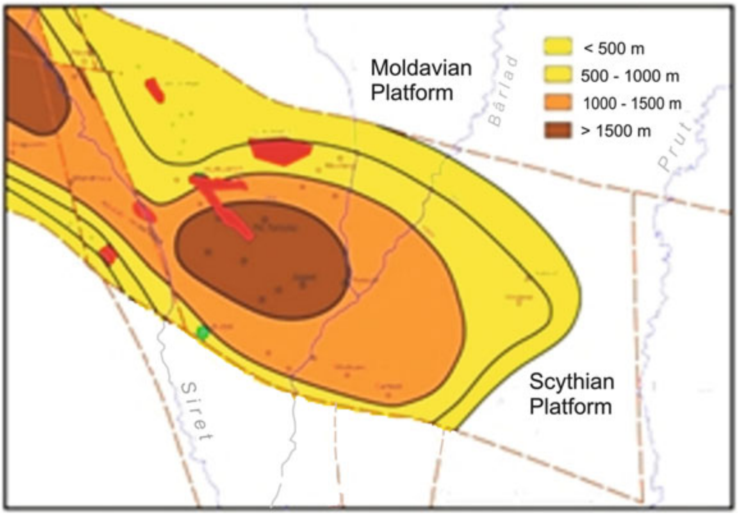

Fig. 8 Isopachs of the source-rock Mandrișca Formation (from [11], modified from [21])

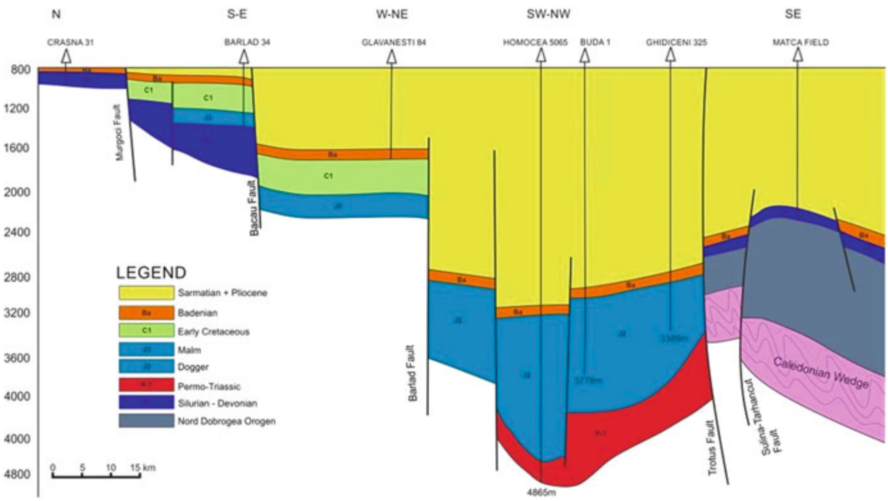

Fig. 9 Cross-section over the Bârlad Sub-basin showing the thick development of the Dogger formations (amended from [3])

Reșita–Moldova Nouă Basin

The Early Jurassic, in Gresten facies, from the Danubian Autochtonous is represented by the Uteriș Formation ([22], emend. [23]) which rests transgressively over older terms. The stratigraphic sequence starts with clastic deposits and laminated mudstones with a coal measure package (100 m in cumulative thickness)

Table 4 Main characteristics of the Moesia and Moldova basin Jurassic AU (from [16, 19], amended from [11])

Plays		Balș AU	Bârlad AU
Basic data	Shale formations	Black shales 75%	Black shales, argillites
	Ramesti & Mandrisca fms.	Silts, sands 25%	Silts, sands 30%
	Geological age	Bajocian–E. Callovian	Bajocian–E. Callovian
Physical extent	Prospective area (km^2)	900	500
	Depth at the top of plays (m)	1,800–4,000	2,200–3,300
	Avg. thickness of the plays (m)	100	500
Reservoir properties	Pressure (Atm)	170	215
	Temperature (°C)	60	65
	C_{org} (%)	0.25–3.11	0.3–2.1
	TOC range (wt.%)	0.1–6	na
	Thermal maturity (% R_o)	0.50–0.6	na
	T_{max} (°C)	437–440	na
	Kerogen	II/I–III	II–III

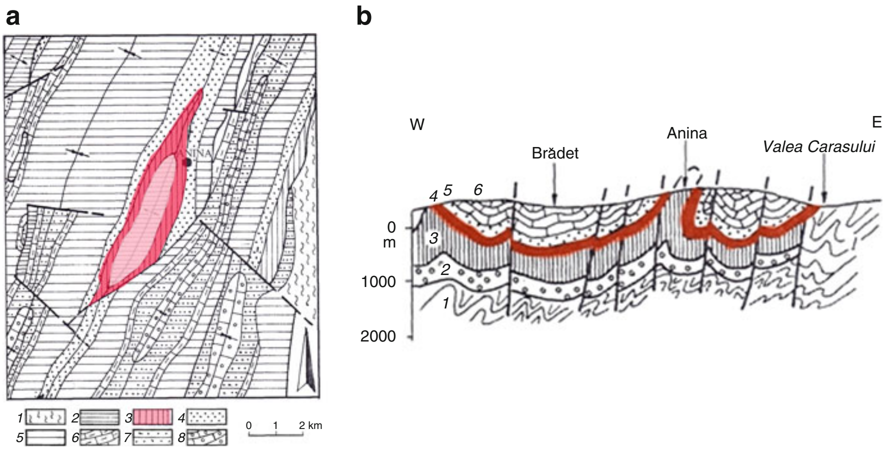

Fig. 10 (**a**) Anina Sub-basin map showing the location of the Liasic coal formations in *red*; (**b**) Cross-section through the Anina Sub-basin. (adapted from [24]): *1* metamorphic rocks, *2* Lower Permian, *3* Lower Jurassic with coal and bituminous shales, *4* Middle Jurassic, *5* Upper Jurassic, *6* Neocomian, *7* Barremian – Aptian, and *8* Upper Aptian

which grade vertically into black, bituminous shales. These fine laminated bituminous shales referred to as a Pliensbachian age are up to 200 m thick unit and have the highest gas shale potential in the Southwestern Carpathians.

The Liassic bituminous shales were drilled by numerous boreholes in the central part of the Reșița–Moldova Nouă basin, and crop out in the core of the Anina anticlinal (Fig. 10a, b). The organic carbon varies from 5 to 25% and the soluble bitumen exceeds in few cases 1–2%. Mineralogical markers into shales are: kaolinite (35–55%), quartz (15–20%), and pyrite (1%) [24].

Eventually, it should be mentioned that a peculiar use of the Uteris shales, quarried at Anina during the late communist period, was the burning in thermocentrals for the electricity production. The project lamentably failed but the in-place reserves for the Anina Sub-basin – that attracted the attention of Falcon Oil & Gas an operator of a former concession in the area – were reckoned at 1 B tons, and for the Doman Block, 300 M. tons.

2.1.3 Cretaceous

The Cretaceous is recognized as a main period for the prolific bituminous formations that sourced conventional oil and gas fields worldwide. In Romania, these formations are often strongly folded and overthrusted. Due to their richness in organic matter and good maturation parameters they could be, at longer term, possible targets for unconventional resources of the Eastern Carpathians foldbelt.

Eastern Carpathians

The Cretaceous formations with shale gas potential have a large development, along the Eastern Carpathians Inner Moldavides. They are bordered in the west by the core Crystalline-Mesozoic Zone or, partially, by the southern sector of the Neogene volcanic and by the external Moldavide Nappe units to the east. The source rocks were studied in outcrop (Fig. 11) and in numerous wells drilled for the conventional hydrocarbon exploration and production in the Carpathian flysch nappes.

In the Eastern Carpathians, internal Flysch Basin, many fine clastic Cretaceous formations have a bituminous (e.g., Black Shale Formation!) character, and could be defined as potential unconventional siliciclastic mudstone continuous plays.

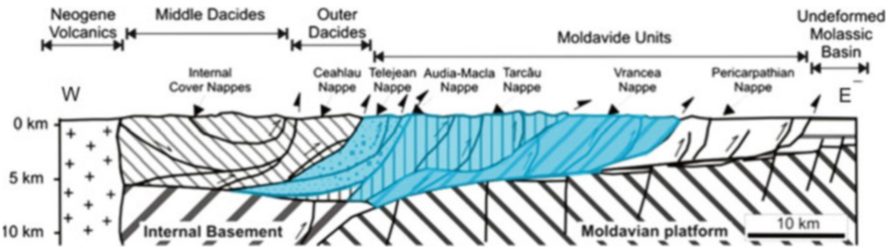

Fig. 11 Conceptual cross-section of Moldavides, from Neogene volcanics to undeformed molasse Foredeep [25]

Upper limit of the play was arbitrarily traced at 2,000 m depth where temperatures would be adequate to generate hydrocarbons [45].

The Teleajen Formation (Hauterivian–Barremian) is a shaly-sandy flysch with thick siliciclastic mudstone intercalations up to 1,000 m in thickness [26] included in large syncline and faulted anticlines. They locally are in the oil and gas window.

The Audia Formation (Valanginian-Albian) develops in a thick black siliciclastic mudstones facies admitting thin calcareous sandstone intercalations in the lower formation section. Also known as the Black Shale Formation, now in the gas window below 2,000 m, it should be of importance for the evaluation of its shale gas potential (Fig. 12 and Table 5).

The anoxic basinal depositional system of this formation shows a number of turbidite fringe lobes along the Eastern basin slope and a siliciclastic, bituminous mudstone facies in the central basin area [26]. The black color of the formation is given by the intimate association between the organic matter and hydro-illite. Some of the minor elements – Cu, Ni, and Co – show relative dependency on the content of argillaceous mineral of the rocks.

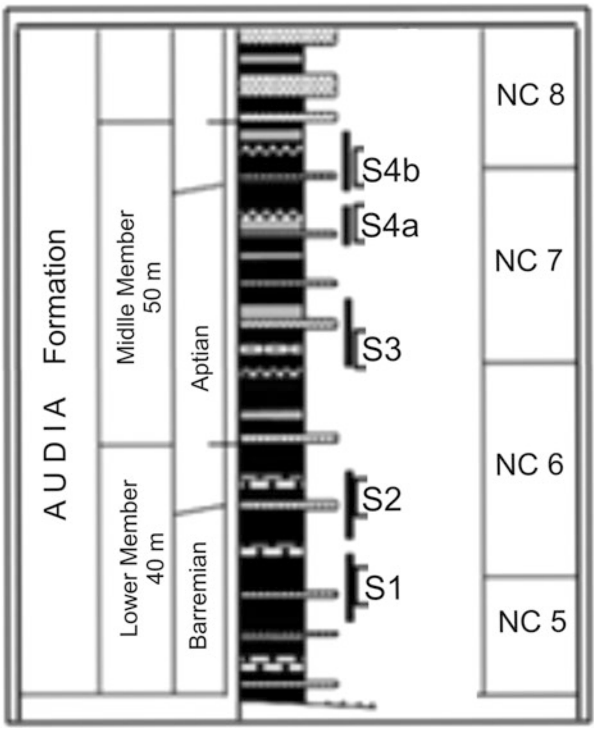

Fig. 12 Composite lithological column of the western flank of Largu anticline (modified after [27]) and biostratigraphy based on calcareous nannoplankton of the studied deposits (S1 up to S5 intervals investigated)

Table 5 Main characteristics of the Eastern Carpathian Cretaceous plays (data amended from [26])

Plays		Teleajen	Audia
Basic data	Shale formations: *Teleajen & Audia fms (= black shales Fm)*	Black mudstones 50%, siltstones and sandstones 50%	Black mudstones 70%, siltstones 20%, sandstones 10%
	Geological age	Hauterivian–Barremian; Albian	Hauterivian–Albian
Physical extent	Prospective area (km^2)	300	200
	Depth at the top of plays (m)	2,000	2,000
	Avg. thickness of plays (m)	750	600
Reservoir properties	Pressure (Atm)	na	na
	Temperature (°C)	120 (est)	125 (est)
	C_{org} (%)	na	0.30–0.84
	TOC (wt.%)	0.8–1.35	0.25–3.35
	Thermal maturity (% R_o)	Upper part of the oil window	0.55–2.02
	T_{max} (°C)	na	425
	Kerogen type	I–II	I–II

2.1.4 Paleogene

The Paleogene is another period rich in bituminous sedimentary formations in Romania, both in the foreland and overthrust units. The Paleogene black mudstones in the overthrust area sourced numerous conventional hydrocarbon fields that have been producing for more than 150 years of published statistics and seen intensive drilling (mostly above the 2,500 m depth mark) and 2D seismic. Recently OMV Petrom seismic has been covering with proprietary 3D significant areas in the western extremity of the Eastern Carpathian Nappe system and their foreland, a region where the Paleogene source rocks are believed still in the expulsion stage. However, as above mentioned, these folded black shales are an unconventional resource development target at long term only.

Although the surface geological knowledge, including source rock parameters, reached a reasonably good stage, the identification of continuous plays and related assessment units remains difficult. Indeed the low geothermal gradient (2.5–3°C/100 m) suggests maturation of organic matter below 4,000 m depth which associated with the advanced tectonization of the Carpathian overthrust nappes in a number of compressional stages and the weak results of the seismic resolution (including at shallow depths) make difficult the selection of the subsurface areas of interest in the Eastern Carpathian Foldbelt. A different situation prevails in the Getic foreland basin and in the Transcarpathian Flysch nappes foredeep where similar Oligocene bituminous siliciclastic mudstones are widespread at lower depths and little folded.

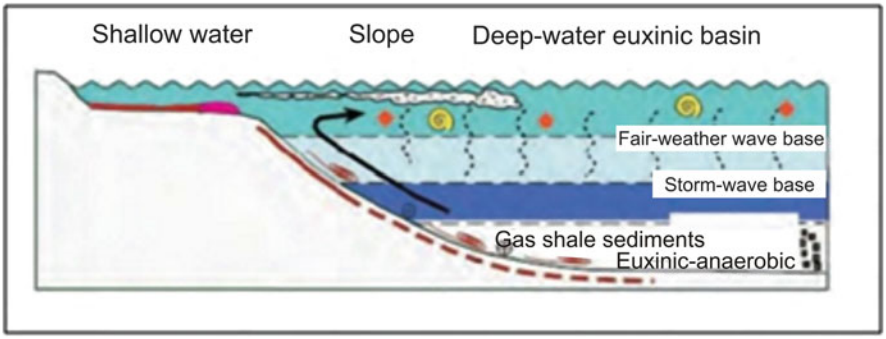

Fig. 13 Facies model for Oligocene Formations from Eastern Carpathians [3]

Eastern Carpathians

The Paleogene bituminous formations belong to the outer Moldavide nappes bordered to the west by the inner Moldavide Nappe system and in the Eastern, by the Moldavian Slope, Scythian, and Moesian Platforms, to the southeast. The Oligocene main formations with a potential shale gas production develop inside the flysch facies suites with the main petrotypes consisting in clay rocks, argillites, silts, dysodiles, menilites, marls, and black carbonate mudstones.

The oil or gas-bearing shales included in each formation may reach between 30 and 200 m and being frequently thinner. Often, they represent associations of mudstone lithological types (shales, argillites, dysodiles, menilites, and marls) alternating with thin levels of brittle sandstones thus increasing the possible technical recoverable estimations The main unconventional oil and gas candidates are the Menilite Formation, Brown Marl Formation, and Dysodile Formation [3]. These predominantly silty mudstones have an overall poor organic matter content because the euxinic environment was limited only to a vertical section (Fig. 13) close to the bottom of the basin [28].

Values of TOC of numerous shally levels are often above the threshold considered as minimum for hydrocarbon generation of oil and gas shale. For instance, the large TOC differences, within dysodile mudstones, between 0.82 and 17.62 underline also an intricate lithologic assemblage of sequences and the diversity of rhythms which characterize the formation in its totality [3, 24]. All the organic-rich intervals subject to analysis revealed T_{max} higher than 420°C that shows that the organic matter is in the oil and dry gas generation window (Table 6).

Maramureș Basin

The Maramureș Basin is on the Romanian territory, a segment of the Transcarpathian Flysch Zone. Here, the Pienide Nappes are thrusted over a Carpathian Late Cretaceous to Early Miocene hinterland in the east and are covered by the Pannonian Basin System Neogene sediments in the west [44]. The Oligocene hinterland mature source

Table 6 Main characteristics of the Eastern Carpathians Paleogene plays

Plays		Vrancea	Tarcau	Maramures
Basic data	Shale formations: *Brown Marl, Dysodile, V. Carelor, Valea, V. Morii fms*	Black mudstones 70%, silicolithes 15%, argillites 10%, sandstones 5%	Black mudstones 70%, silicolithes 20%, sandstones 10%	Black mudstones 70%, siltstones 20%, sandstones 5%, silicolithes 5%
	Geological age	Oligocene–E. Miocene	Oligocene–E. Miocene	Oligocene
Physical extent	Prospective area (km^2)	na	na	750 est
	Depth at the top of plays (m)	2,500	2,500	2,500
	Avg. thickness of the plays (m)	500	750	250
Reservoir properties	Pressure (Atm)	na	na	na
	Temperature (°C)	70 (est)	70 (est)	70 (est)
	C_{org} (%)	na	0.35–2.5	6
	TOC (wt.%)	0.79–6.64–12.69	0.82–17.62	2–10%
	Thermal maturity (% R_o)	0.74–0.65	0.47–1.10–1.15	0.86
	T_{max} (°C)	415–450	407–422	na
	Kerogen type	II–marginal mature	I–II, oil prone	II (est)

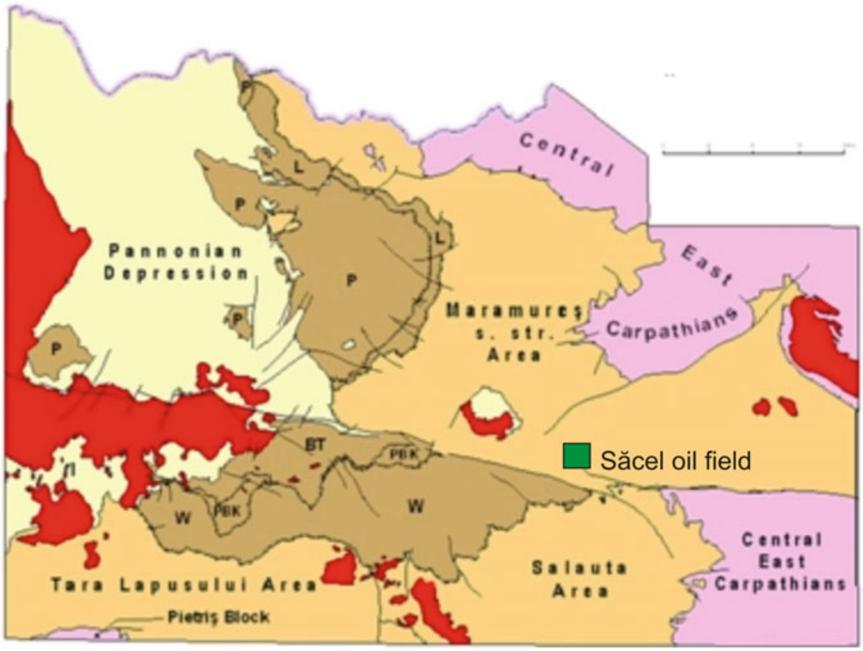

Fig. 14 Tectonic sketch of the Transcarpahtian Flysch Zone showing in light orange the area of prospective shale development (courtesy of Zeta Petroleum; prepared for Zeta by Sandulescu in 2010)

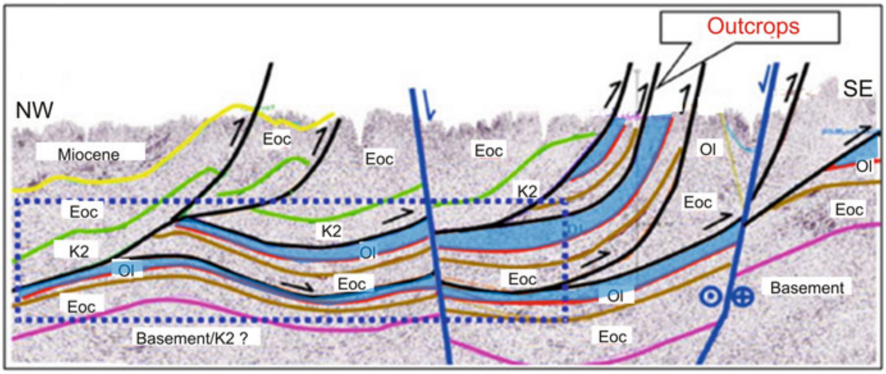

Fig. 15 Maramureș Basin Oligocene black mudstone sequences (top in *red*). *Dotted rectangle* shows the unconventional shale prospective section inside and beneath the nappe development area (from [1])

rocks sourced numerous oil seepages and the Sacel oil field. This paper refers to the potential unconventional Oligocene shale play of the Maramureș Basin *s.str*. (Figs. 14 and 15) beneath and just east of the outcropping nappe line.

The Paleogene sedimentary sequence of the Maramureș Basin includes the bituminous Valea Carelor Formation (Rupelian) and Valea Morii Formation (Rupelian-Chattian) separated by the Birtu massive sandstones. Lithology of these formations recollects the dysodile/menilite facies above described.

Geochemical analyses indicate the presence of the rich source rocks (Table 6) with a total hydrocarbon content in the rock reaching up to 5,000 ppm. With an oil window at about 2–3 km [1] when buried under the Pienide thrust sheets (Fig. 15), these parameters could make this play an attractive oil shale play.

Another occurrence of Oligocene black mudstones is the Ileanda Formation from NW Transylvania homocline, probably a lateral facies equivalent of the Valea Carelor Formation from Maramureș. An outcrop sample shows a TOC of 1.7 (wt.%), Tmax of 420°C, and HI 347 mgH/gTOC [29] while the coeval Tard Clay Formation from Hungary, a kerogen type I–II source rock shows somewhat lower geochemical parameters.

Although most of the modern maturation studies showed that the Ileanda shales are mostly immature [30] it must be mentioned the occurrence of heavy oil in the continental redbeds from the Jibou area produced in pits [29] dug in the late nineteenth century. The oil could well come from the Ileanda bituminous shales when were buried at depths below 2,500 m then migrating updip on long distances, towards the basin margin. Alternatively, a possible bituminous basinal development of the Rona Limestone Formation or bituminous facies in the subjacent Cretaceous might be possible source rocks for the jibou oil intriguing occurrence.

Getic Basin

The Getic Basin is located in the foredeep of the South Carpathian thrust belt and corresponds to the Paleogene–Early Miocene strike slip basin forming structure [1] subsequently thrusted over the Moesia along the Pericarpathian Line in the Sarmatian (Figs. 16 and 17).

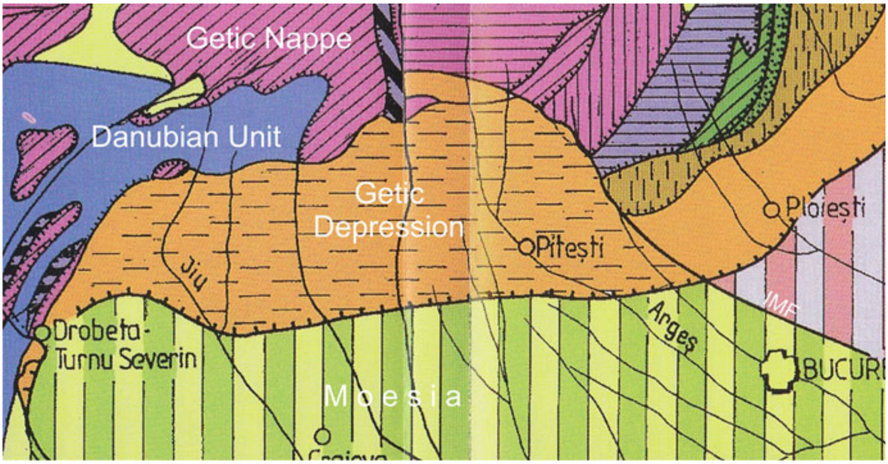

Fig. 16 Getic Depression develops west of the Intramoesian Fault and is bounded by Danubian Unit, Getic Nappe, and Moesia (adapted from Mutihac and Mutihac 2010)

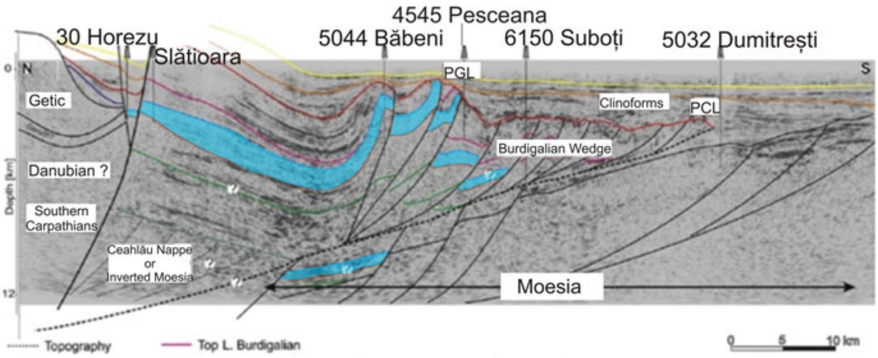

Fig. 17 Cross-section in the central part of the Getic Depression showing in blue the Oligocene black shale package (from [49])

According to lithological criteria and regarding the content of organic-rich facies (known in Romania as the Pucioasa Facies), only two formations may be considered as having oil and gas-bearing potential in the basin: Olănesti Formation and Brădulеț Formation (Table 7) [47].

The Olănesti Formation has two members: the lower member has a maximum thickness of 40 m, and includes shales with pebbles and cobbles or conglomeratic intercalations. The upper member is thicker and comprises shales, silts, sublithic sandstones, and microconglomeratic facies. The Brădulеț Formation, developing in the Doamna and Vâlsan rivers area, has significant facies variations (from rudite to lutite) from west to east and could display up to 80% *bituminous shale* sections, similar to the Pucioasa Facies in the Eastern Carpathians.

Table 7 Main characteristics of the Getic Basin Paleogene plays

Plays		Olănești	Vâlsan–Doamna
Basic data	Shale formations: *Olănesti &, Brădulet Fm*	Black mudstones 70%, sandstones 25%, conglomerates 5%	Black mudstones 80%, sandstones 20%
	Geological age	Lutetian–Priabonian	Late Chattian–Burdigalian
Physical extent	Prospective area (km^2)	700 (est)	2,500 (est)
	Depth at the top of plays (m)	2,000	2,000
	Avg. thickness of the plays (m)	350	300
Reservoir properties	Pressure (Atm)	na	na
	Temperature (°C)	75 (est)	70 (est)
	C_{org} (%)	2–4.54	2.31–6.82
	TOC (wt.%)	0.72–1.18	1.80–2.25
	Thermal maturity (% R_o)	0.49	0.33–0.67
	T_{max} (°C)	416	417–424
	Kerogen type	II–III	II–III

Depositional systems in the Eocene–Oligocene time correspond to an open-marine environment with warm and well-oxygenated surface waters that changed from an anoxic to a hypoxic environment.

Regarding the hydrocarbon potential Grasu et al. [24] specified that in the core samples taken in the northern area of the basin, the organic matter is immature, having only a weak gas-bearing potential. As the organic matter content is significant in the southern basin area, a good gas expulsion potential below 2,500 m is likely.

2.1.5 Neogene

Conventional petroleum systems in all tectonic units of the country could have a Neogene source rock. It sourced numerous oil and gas accumulations holding the greater part of national resources [29] with an economic output since the nineteenth century. Predictably they generated interest for their related unconventional resource potential evaluation as well. New unconventional plays were developed in conjunction with the exploration maturation (tight gas) or since the early exploration periods (tar sands) while new plays (e.g., basin-centered gas) await evaluation and exploration work. Below are examples of such unconventional plays located mainly in the Miocene clastics.

Transylvania

The Neogene Transylvania Basin is one of the Neogene central Paratethys Basin systems lying on the Tisza–Dacia terrane. The main distinctiveness of the Transylvania Basin is the presence of a continuous Badenian salt layer which caused the initiation of diapir structures in the Late Neogene movements [31]. Tight gas play was explored in the lowermost clastic suites, above the salt layer in sands with permeability below 1 mD and porosity under 10%.

While the conventional gas has been produced for more than a century from the so called Gas Formation (Late Badenian-Pannonian), for more than 100 years, some unconventional tight gas the unconventional tight gas has been produced in the last decades (e.g., [32]) only. In the central, deeper area of the Târnave Sub-basin (Fig. 18), the top of the Badenian and lowermost Sarmatian (or "Buglovian" in the industry jargon) has been actively evaluated and explored for the tight gas sandy marl reservoir production since late last century. Source rocks being in the gas window open good perspectives for the exploration of the "basin centered" gas, actually, the gas located in synclinal area between the domal areas filled with conventional gas.

Radu and Sorescu [32] distinguished a number of sub-plays (Fig. 19) related to the conventional gas producing fields: (1) inside conventional gas field area, (2) outside the conventional gas field area, (3) in permeability barrier traps, and (4) basin-centered gas (considered as a speculative play at the time being).

Expulsion of thermogenic (?) gas started from the average lean TOC, gas-prone clastics started in the Badenian–Early Sarmatian at onset temperatures of minimum 150°C [33] (Table 8).

Pannonia

The Pannonian Basin is also one of the Neogene Central Paratethys Basin systems that extends over two terranes: Tisza–Dacia and ALCAPA separated by the mid-Hungarian Lineament. The Romanian sector lies mainly over the Tisza terrane and contains a number of extensional basins and sub-basins depocenters. Their final depositional architecture was modified by subsequent strike slip faults and recent inversion. At least two types of unconventional resource plays were identified: basin-centered gas and tar sands.

The area of better development of the basin-centered gas plays in the Romanian sector is located, from north to south, in the following main sub-basins: Abrămuț–Derecske, Socodor–Bekes, and Tomnatec–Mako (Fig. 20). In the latter sub-basin, the basin-centered gas has been in the initial stage of exploration in Hungary by MOL, Exon, and Falcon Oil & Gas where numerous hydrocarbon shows were reported at high depths (Fig. 21).

The Badenian–Sarmatian source rocks (Endröd Formation, in Hungary) and migration are not an exploration risk, as proved by numerous oil and gas fields

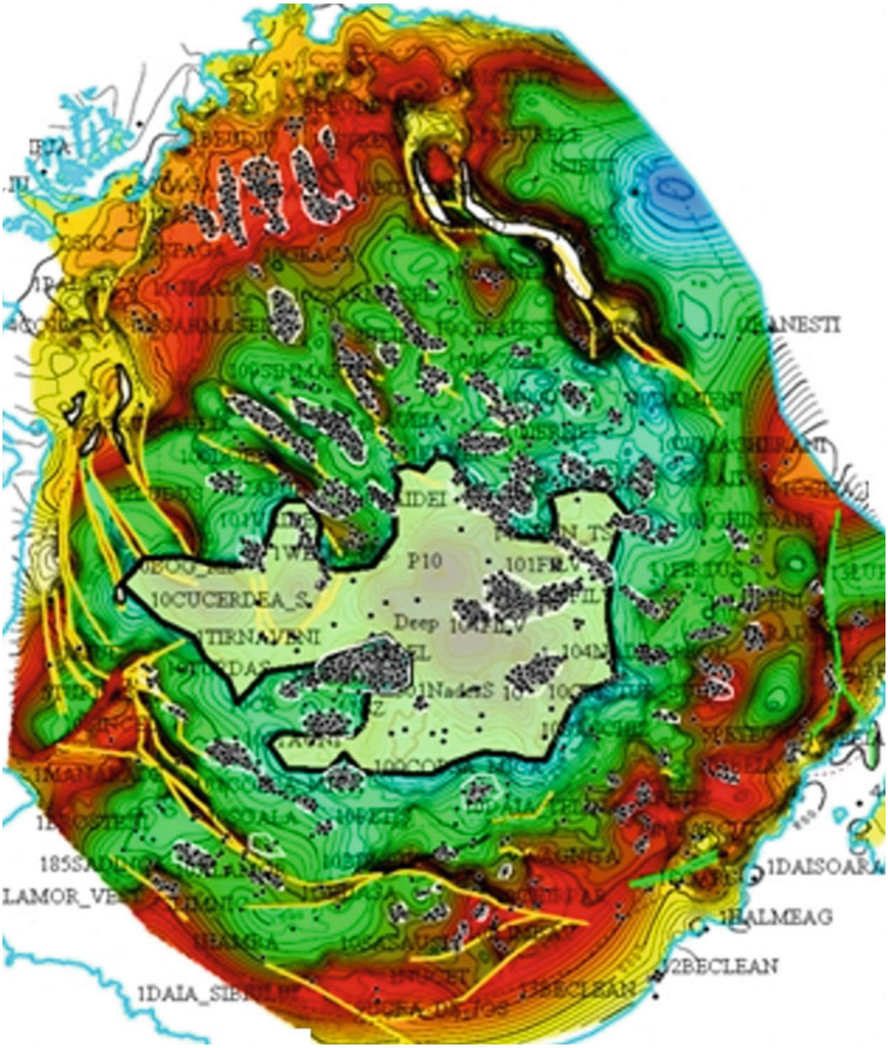

Fig. 18 Area of maximum tight gas play development in light green (from [32])

found in all of the above mentioned sub-basins and separating highs. It is believed that the rapid post-rift subsidence and high temperature gradients are the best ingredients for large amount of gas generation, including in the basin-centered tight sands.

Tar sands were found and produced since the sixties of twentieth century, on the northern slope of the Rez Mountains. This peculiar occurrence of an unconventional play is the Suplacu de Barcau tar sand accumulation (Fig. 22) the world's largest in situ combustion project. The Sarmatian unconsolidated sand is located in a 5^0 north deeping homocline producing from a 10m net pay that contained

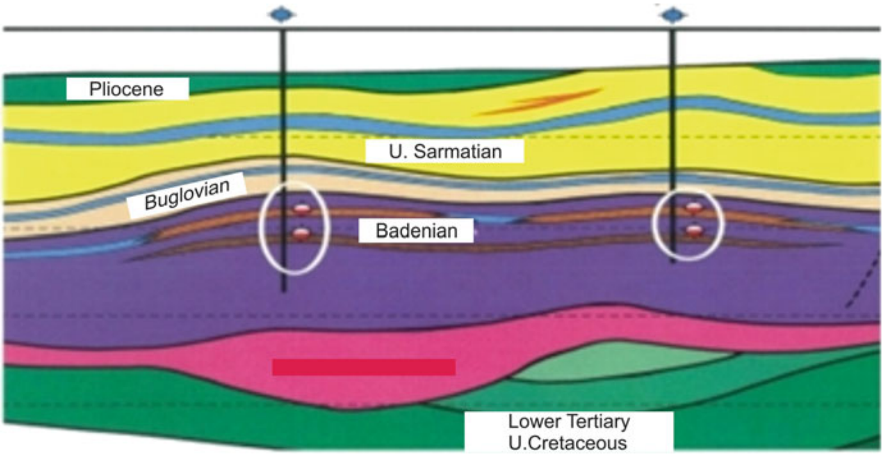

Fig. 19 Conceptual model for identification of tight and basin-centered gas below dashed blue line in both domes and in-between synclinal areas of the Târnave Sub-basin (from [32])

Table 8 Main characteristics of the Transylvania Basin Miocene tight gas AU (amended from [32])

	Plays	Târnave
Basic data	Tight Gas Formations: *Dobarca Fm*	Marls 60%, silts 30%, sands 10%
	Geological age	Badenian–Early Sarmatian
Physical extent	Prospective area (km^2)	1,000
	Depth at the top of targets (m)	2,000
	Avg. thickness of the plays (m)	50
Reservoir properties	Pressure (Atm)	250
	Temperature (°C)	60
	C_{org} (%)	0.5
	TOC (wt.%)	0.14
	Thermal maturity (% R_o)	0.55–1.2
	T_{max} (°C)	423–436
	Kerogen type	II–III
	Volume factor Bg	0.0040

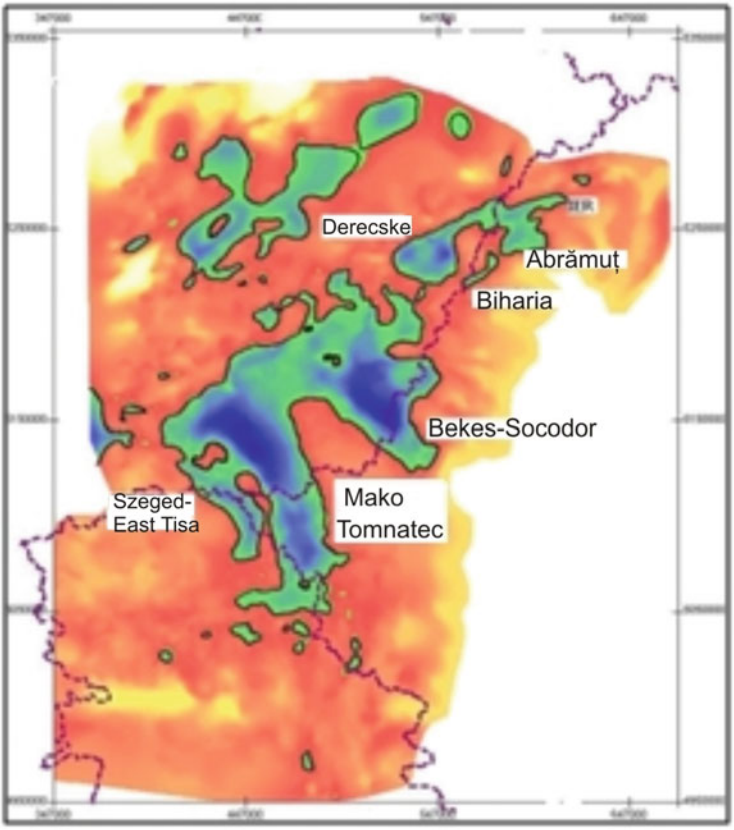

Fig. 20 Location of the Abrămuț–Derecske, Socodor–Bekes, and Tomnatec–Mako basins in the Pannonian basin systems (courtesy Zeta Petroleum)

295 Mbbl OOIP [35]. The Sarmatian tar sand play extends over 15 km width between Suplacu and Derna–Budoi. The production depth varies between 50 and 250 m from sands with porosities of 32% and permeabilities of 1,700–2,000 mD. The estimate of the final recovery factor is estimated to be 55% (Table 9).

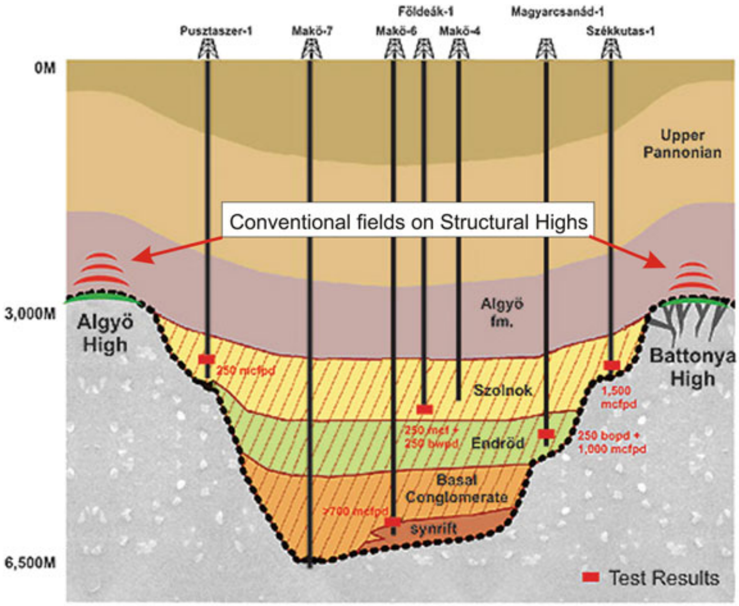

Fig. 21 Cross-section in the Mako–Tomnatec Sub-basin showing the location of conventional hydrocarbon field and the basin-centered tight gas play drilling in Hungary that recovered good oil and gas shows (from Falcon Oil & Gas website)

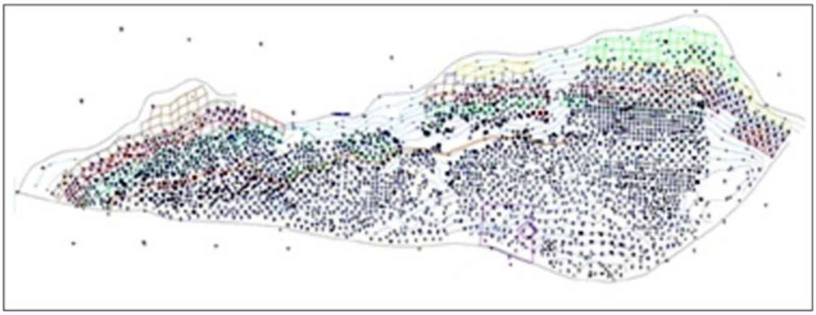

Fig. 22 Suplacu de Barcau heavy oil sand development (from [34])

Table 9 Main characteristics of the Pannonian Basin AU (modified from [36]; Veliciu, unpublished data; [11])

Plays		Tomnatec–Mako			Socodor–Bekes	Abrămuț–Derecske
Basic data	Tight Gas Formations: *Badenian, Sarmatian, Pontian*	Shale: 50%; sand: 50%	Marls: 50% sand: 44%; shale: 6%	Sand: 80%; shale: 20%	Marls: 61%; shale: 23%; sand: 16%	Sand: 70%; shale: 30%
	Geological age	Badenian–Lower Sarmatian	Pontian	Badenian–Lower Sarmatian	Pontian	Badenian–Lower Sarmatian
Physical extent	Prospective area (km^2)	2,250	500	1,000	400	800
	Depth at the top of plays (m)	1,900–3,200	1,900–2,800	2,300–2,600	1,150–2,050	2,400–2,800
	Avg. thickness of the plays (m)	60	200	180	300	65
Reservoir properties	Pressure (Atm)	35	22	27	20	20
	Temperature °C	107	107	100	100	125
	C_{org} (%)	na	na	na	na	na
	TOC (wt.%)	0.62–2.58	1.0	1.2	0.8	0.72–1.45
	Hydrogen Index (mgHC/g TOC)	205	185	210	218	190
	Thermal maturity (% R_o)	0.74–1.92	0.4–0.86	0.32–0.93	0.37–0.42	0.42–0.62
	Kerogen type	II–III	II–III	II–III	II–III	II–III
	Volume factor Bg	0.00380	0.00667	0.00533	0.00875	0.00804
	z-factor	0.998	1.1	1.097	1.2	1.15

2.2 Coal Bed Methane

In recent years, the worldwide coal exploration and mining has been growing faster than the renewable, nuclear or oil and gas as world's energy source attracting a special attention to their multiple recovery methods potential. In Romania, one of the by-product recovery opportunities, the Coal Bed Methane (CBM) has not really started although two foreign companies applied for rights. Only Pannonian International had rights over 87 km^2 in the Petroşani coal basin since 2002 which were subsequently been relinquished after one well drilled and not fracked.

In absence of any result from wells fractured for this purpose, this section will describe only the main properties of Romania's coal measures (Table 11) grouped by age and by geological units following the pattern used for the sections above (Table 12).

The major coal formations are spread over the whole Romanian territory, in various tectonic units and age range:

– Late Carboniferous: *Lupac, Secu* (Reşiţa Basin) sau *Baia Nouă* (Sirinia Basin);
– Early Jurassic: *Anina, Doman, Cozla, Bigăr, Pregheda, Chiacovăţ* (South Carpathians);
– Late Cretaceous: *Rusca Montană;*
– Oligocene: *Petrila, Lonea, Vulcan, Paroşeni* (Petroşani Basin);
– Miocene: *Bozovici;*
– Pliocene: *Husnicioara – Motru, Filipeştii de Pădure* (Dacic Basin).

The known conventional coal resources are located in thrust and foldbelts, in the foreland and post-tectonic basins (Fig. 23 and Table 10). Out of numerous occurrences listed above, many perhaps have no CBM potential.

The only attempt to explore the CBM potential of coal measures in Romania took place in the Petroşani basin (Fig. 23 and Table 11) as mentioned above. Farminee Falcon Oil & Gas drilled the Lupeni South 1 to Coal Seam no. 3, 13, and 14. Primary target seam no 3 was found 21 m thick over the 309–330 m interval. Core analyses and desorption measurements indicate the potential presence of CBM. This well was suspended for fracking which actually never took place.

Another candidate for CBM exploration would be the Anina coal field. The coal seams belong to the Steierdorf Formation from the Lower Jurassic period (Hettangian–Sinemurian) of the Resita–Moldova Nouă Basin (Fig. 23). This bituminous coal formation would meet the following critical criteria for several CBM options [23]:

(a) the CBM reserves are considerable, taking into account the mining history of this area, that also confirms a massive and permanent generation of CBM in the underground;

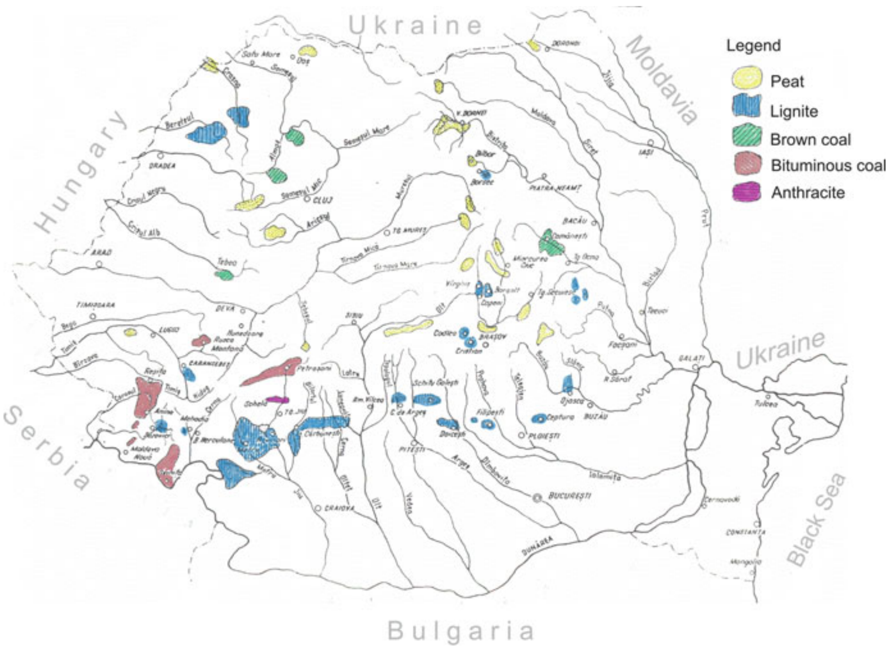

Fig. 23 Map with geological sketches of the main coal basins in Romania (from [3])

(b) the natural sequence of the CBM mining options in the Anina area, considering its geological structure, the formation's stratigraphy, and its coal reserves, is the AMM (Abandoned *Mines Methane*) option;

(c) the additional cracking of the shales is an advantage for the CBM mining using the AMM and UM options.

Table 12 shows the main coal resources and remaining reserve on 01.01.2014 from fields that could be good candidates for CBM evaluation.

2.3 Gas Hydrates (Clathrates)

The long time known accumulations of gas hydrates in the West Black Sea basin (Fig. 24) are located along the euxinic threshold with the largest concentrations offshore Romania and Ukraine. The euxinic threshold area represents the limit between the continental shelf and the continental slope, at an approximate depth of 220 m. Clathrates are found at 15–30 m below the seabed surface. The distance from the coast can be shorter (3 km offshore Bulgaria) and bit longer 50–100 km (offshore Romania). As an unconventional resource, gas hydrates, known to embody huge global reserves, still raise unsolved economic production solutions, both in terms of technology and environmental protection [46].

Table 10 Coal deposits from foldbelt, foreland, and tertiary back-arc units

Period	Ma	Foldbelt Unit		Foreland Units		Tertiary Back Arc Units	
		East Carp.	**South Carp.**	**Dacian Basin**	**Comanesti Basin**	**Pannon**	**Petrosani**
Quaternary	1						
Pliocene	5	Lignite		Lignite		Lignite	
Miocene	23		Brown coal, Lignite		Brown coal	Lignite	
Oligocene	33						Bituminous coal
Eocene	55						
Paleocene	65						
Cretaceous	145		Bituminous coal			Brown coal	
Jurassic	199	Brown coal	Bituminous coal				
Triassic	251						
Permian	299						
Carboniferous	359		Bituminous coal				
Devonian	416						
Silurian	439						
Ordovician	488						
Cambrian	542						
Proterozoic	2500						
Legend:		Bituminous coal		Brown coal		Lignite	

Gas hydrates accumulation from the Black Sea occurs usually in the structure of submarine turbiditic fans (i.e., in the coarser sediments filling the buried channels). Fans can be related to fractures [38]. Shimkus et al. [39] show that gas accumulations could also be located in alternating layers of silts and sands with horizontal stratification, covered by impermeable clay layers. Gas-saturated mud layers have also been identified (Fig. 25).

In the western part of the Black Sea, there are the main two geologic and geochemical indicators that help locating gas hydrates: mud volcanoes and the high concentration of methane dissolved in the water [38]). The equivalent volume of methane of the hydrate accumulations was calculated. They are estimated [38] at:

- $12 \pm 3 \times 10^{11}$ m^3 methane for the abyssal cone of the Dnieper;
- 6.945×10^8 m^3 methane for the abyssal cone of the Danube;

According to Vassilev and Dimitrov [40], the surface covering the presence of gas hydrate reserves likely covers 288,100 km^2, represents 68% of the total area of the Black Sea. The volume of methane was estimated at 1–5 T m^3.

Table 11 Main characteristics of the bituminous coal from the Petroşani Basin

Age	Location/unit	Deposit name	Coal seam id = thickness (m)	Gross calorific value (kcal/kg)	Maceral group
Bituminous coal (Houille-fr; Huilă-rom)					
Oligocene–Miocene	Petroşani (0–21 coal seams); economic important: 3,4,5,7,8,9,13, 14,15,17,18			Low: 2,500–7,200 High: 3,000–7,700	Vitrinite (telinite, collinite) = 75%; Exinite (cutinite, rezinite, sporinite, liptodetrinite) = 10–30%; Inertinite (semifusinite, fusinite, scklerotinite, micrinite) = 0.1–8%
		Aninoasa	3,5,7,13,15,18	5,500	
		Câmpul lui Neag	8,9 = 4.5; 13 = 13; 14 = 10; 17,18 = 4		
		Livezeni	3,5		
		Lonea	3,5		
		Lupeni	3 = 6–30; 5 = 8; 6–7 = 2; 8–9 = 0,7–1.3; 13 = 1–3; 14 = 1.4; 15 = 1.6; 17 = 0.7; 18 = 1.2	6,200–7,500	Vitrinite (60–91%, exinite (4–34%), inertinite (1%)
		Paroşeni	18, 15 13		
		Petrila	3,4,5,7,8,9,12,13		
		Sălătruc	1,4		
		Uricani	3,5,8,9,13,14,18		Vitrinite (63–92%), exinite (30%), inertinite (1%)
		Vulcan	3,5,7,13,15,18		

The very low international price of the oil barrel and BTU of gas in 2015–2016 cooled down the exploration enthusiasm for most of the unconventional plays in Europe that would require USD 50/bbl for larger scale, new economic production projects. The downturn in prices that leads to a stagnation of worldwide industry activities has not bypassed the allegedly rich unconventionals of the Eastern and Central Europe. Romania's nascent interest for these resources was stopped brutally hoping for a resumption of the research in better oil and gas price days.

Table 12 The main coal fields, and their resources in Romania

Coal grades	Resources/ reserve	Gross calorific value (Kcal/kg)	Coal fields
Anthracite	69 Mt	6,230	*Schela, Viezuroi*
Bituminous coal	1,416 mil t/602 MM t	3,596	*Petroşani Basin Fields*; *Banat (Lupac, Secu, Doman, Anina*
Brown coal	38,828 10^3 t	2,796	*Ţebea, Sălaj, Comăneşti*
Lignite	9.65–3.29 B t	1,717	*Rovinari, Jilţ, Tismana, Motru, Berbeşti, Sălaj, Filipeştii de Pădure, Şotânga*

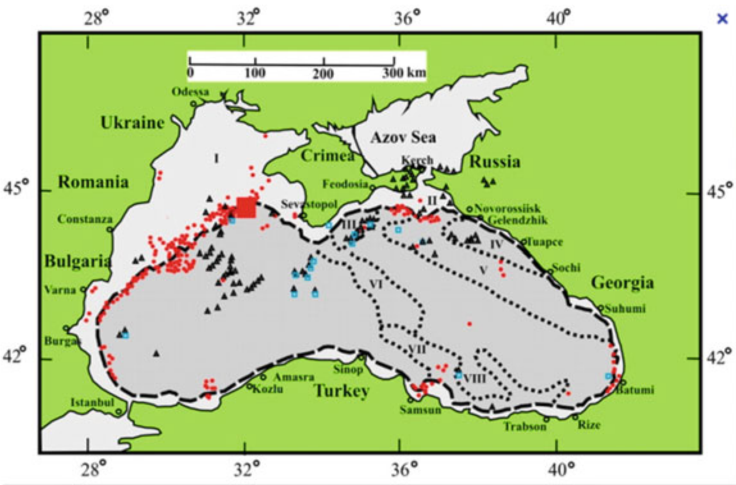

Fig. 24 Location of the possible accumulations of gas hydrates in the Black Sea (http://sp.lyellcollection.org). Key to symbols: *black triangles* – mud volcanoes; *red dots* – gas seeps (from [46])

Summing up the most recent evaluations of the unconventional resources of Romania for various types of plays and assessment units (AU) so far it appears they could reach a revised value of technically recoverable resource of 1,000 billion m^3 of gas and 500 million bbl of crude oil (Table 13). This compares with the latest EAI [41] estimations of 1,444 Bm^3 of gas and 300 M bbl of shale oil and condensate technically recoverable or to previous local 2,150Bm^3 of gas and 525 Mbbl of oil [11].

3 From Exploration to Production: Geological, Political, and Environmental Challenges

A number of years passed since IEA heralded in 2011 that our civilization could enter the “Golden Age of Gas” persuaded that the outlook for natural gas is bright, among others because the newly demonstrated profitability of the development of the “vast resources” of unconventional gas. A year after, the agency published [42]

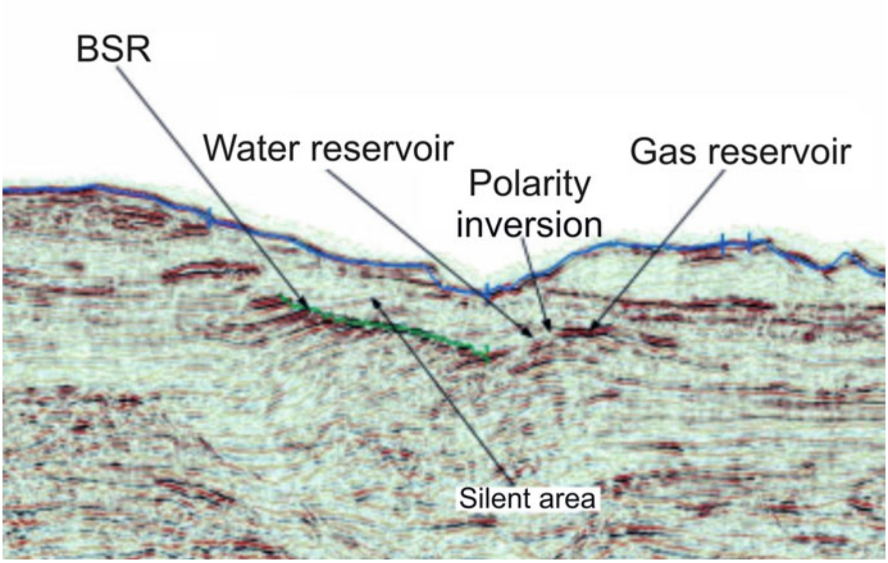

Fig. 25 Seismic time cross-section showing the lower limit (BSR) of a gas hydrate accumulation offshore Romania, in the euxinic threshold area (from [37])

the Golden Rules for the Golden Age of Gas. Facing growing public concern, IEA strong of its international energy reserve and production monitoring strength combined with its vision of the world's need for a greater energy supply was attempting to signify public opinion that their concerns are addressed and manageable. A number of principles – drawn upon consultations with world high-level stakeholders – especially those related to the surge in the industry's activities related to the unconventional gas production at that time, were developed for the use of the "policy-makers, regulators, operators, and others."

The life realities showed that future is still a difficult business to predict. The unconventionals' fever has been fading since for a number of conjugate reasons. The severe downturn of petroleum industry and the revivals of political tensions between the gas consuming countries of the Western Europe and the gas supplying Eastern Europe and Asia made difficult the preparation of short and medium term strategies even for countries used with this exercise. Moreover, the sluggish European countries economy face now an oversupply of gas and electricity power driving prices of these commodities to record lows. In this intricate situation, almost all major projects of unconventional resource development were shelved in Poland, Ukraine, and Romania.

Not many countries in Europe have presently a clear vision for the next 3–5 years nor longer term strategies dedicated specifically to the unconventional resource development and generally for a sustainable energy supply and consumption. Unsurprisingly, Romania is not an exception even though the future local conventional production forecasts are dull. Challenges for setting up of a strategy

Table 13 Unconventional Resources of Romania (End 2015)

Play	Risked GIIP (B m^2)	Technically recoverable[a] (B m^2)	Risked OIIP (B bbl)	Technically recoverable[a] (B bbl)
Transylvania Tight Gas	125[b]	20[c]	0	0
Pannonia Tight Gas	3,000	100	0	0
Carpathian Shales	na	–	na	–
Foreland Tertiary Basins	na	–	na	–
Foreland Jurassic Shales	1,050[b]	285[b]	6[d]	0.3[d]
Foreland Paleozoic Shales	1,150[c]	600[c]	1.6[d]	0.08[d]
Heavy Oil Tar Sands	0	0	0.259	0.1
Gas Hydrates	na	–	–	–
Coal Bed Methane	na	–	–	–
Total (rounded off)	5,000	1,000	8.0	0.500

Assessment according EIA and USGS methodology
[a]Producible with current technologies, regardless of other costs, [b]Radu and Sorescu [32], [c]Popescu and Veliciu [6], revised, [d]Kuuskraa et al. [41]

for unconventional resource development are threefold. The *geological* challenges are related to paucity of modern data and therefore, the incipient knowledge and understanding of these plays. The *political* challenges for potential unconventional resource investors in the local situation are quite dense. Due to a quasi-total absence of governance in this domain, there has been an actual lack of commitment to regulate better the unconventional activity and risks. The *environmental* challenges already passed through very strong public and administration debates, evaluations, and analysis tough with no returns in the specific regulatory legislation.

No appropriate regulations were yet devised in Romania in spite of bureaucrats' lip-service while internationally, many governments reached conclusions that unconventionals can be safely developed and produced and keep on working for their capitalization. Facing this persistent and undesirable reality, the industry chooses to be involved in common efforts with think tanks like the EFOR, Energy Policy Group, Energynomics, RO*e*C, and others or setting-up organizations such as Romanian Petroleum Exploration and Production Companies Association (ROPEPCA) aiming to enhance an interaction with the main hydrocarbon industry stakeholders: policy-makers, regulatory agencies, nongovernmental organizations, and civil society.

3.1 Geological Challenges

Numerous geological and engineering issues are equally spread over the full chain of unconventionals operations: evaluation, exploration, development, and production. In Romania this frontier energy area is in the initial resource evaluation phase; only one exploratory well was completed in 2014 and abandoned with tight results. A number of particular local questions are described below.

Geological minimum requirements for defining assessment units or at least larger areas with probable exploration potential are partly available only in the Romanian geological literature and have obviously been extensively used in our evaluations. As much as possible main characteristics used for evaluation were mapped. However, many basic required data are simply missing not mentioning that the available ones are often partial and come from various vintages sources and some of them bear uncertainties. Moreover, due to the novelty of the exploration for continuous resources in Romania, a comparison of our evaluations with analogs of the same sedimentary basin is not practicable; the comparison models used in Romania come from the better-known plays of Poland, Ukraine, and the USA.

Technically speaking Romania has been a producer of unconventional hydrocarbons since mid-last century and this was possible because of successful application of best world technologies available that time to the production of these unconventionals: fracking and underground combustion. First fracking was performed in Romania (third country in the world) in the conventional oil accumulations of the Carpathian Foldbelt in 1954, then started to be applied on large scale in all petroliferous basins and since then hundreds of such operations were performed. Time passing since the industry privatization coupled with the lack of re-technologization, it appears that the Romanian service industry is currently only partly capable for implementing modern, large fracking programs. After all, the local service industry is also fully dependent on the internationally regulated price of the oil barrel!

This study allows some first comments on Romania unconventional oil and gas shale resources evaluation and their geological challenges:

– Relatively small sedimentary basins;
– Minimum geochemical requirements for the shale play evaluation were not always met in our assessment units, e.g., TOC (wt.%) > 1, $\%R_o > 1$, $T_{max} > 420°C$, etc., as well as the scarcity of public domain important indices such as HI, OI, and PI;
– There is a lack of constraints on: siliciclastic and carbonate mudstone mineralogy, diagenesis, geomechanial information such as fracability index and brittleness;
– Doubts on depth of top and base of mature shale intervals from the definition of assessments as well as on the organically rich shales heterogeneity or their regional gross and net thickness hence hampering the accurate delineation of assessment units;
– Correct understanding of the depletion and recovery factors is evidently missing therefore there are difficulties in evaluating reserves.

An improvement of our technically recoverable resources evaluation could however be obtained at short term if NAMR will remove its excessive classification regime of following data: 2D and 3D seismic, well log suites, access to cores from the 2,000–4,000 m depths, and pyrolysis results.

There are, on the other hand, some positive aspects related to unconventional resource exploration in Romania such as: relative low population density and availability of services and qualified workforce; local availability of water and sand or other propants; present lower operation costs and lower concession costs (thus far!).

3.2 Political and Administrative Challenges

On the local political scene there are at best, three major obstacles for companies that wish to test country's unconventional resource potential: (1) the unceasing practice of unpredictable changes of public policies showing the actual lack of a political driving force on this matter; (2) the absence of long-awaited adequate regulations for the full exploration and production chain and (3) the unimaginative accelerated enactment of numerous "temporary" additional taxes on the concessionaire investment and not on its profit.

The year 2016 seems to see first thoughtful steps to improve the misfortune of the petroleum industry that it has been facing in the last years. The Romanian Academy finalized in February 2016 the major study: Romania development strategy for the next 20 years – natural resources strategic reserves. This together with projects for change proposed by ROPEPCA and other think tanks is being in public consultation and will be amalgamated by the Ministry of Energy which must propose to the government a strategy for the national energy 2016–2036 not later than August 2016. It is rumored that the resulting official documents will have a special place for legislative changes aiming at attracting investment, open land access rules, declassification of technical information, a new taxation system of profits (and not of the investment) as well as unconventionals exploration practices, all with hopefully resulting positive economic and social impacts. Finally, it appears that some Romanian policy-makers are open to revise the royalty split between the state budget and the communities thus raising the probability of a resumption in general of the petroleum industry activity in Romania of the following years.

Possible activities related to unconventionals E&P are regulated by petroleum law 238/2004 and application norms 2975/2004 which do not differentiate between conventional and unconventional gas that in principle is acceptable. One of the important clauses of this law is the stability of contractual terms and the application of the most favorable terms in the case of subsequent legislative changes which bring comfort to titleholders. There are however major problems related to the hands-on application of this law and the secondary legislation terms. One of these is associated with the permitting variously interpreted by countryside authorities. They arbitrarily oppose the legal right for leasing the underground nation's wealth to a variable and discretionary access to land. Another one vividly discussed lastly in the Parliament commissions that involved the Ministries of Finance and Energy as well as the local ROPEPCA was the setting up of a new royalty scheme which seems not practicable due to all present contracts stability clause.

The state body called to apply the petroleum law is the NAMR which has the power to offer and sign concession agreements, to decide the schedule of operations, methods to be used in each seismic, drilling, or production operation as well as to monitor all these activities. In reality, badly unstaffed and politically dependent, NAMR delays vital decisions the industry would expect from an independent and professional state agency. Corroborating some of the industry claims and proposals would be helpful if – on a basis comparable to those of the Norwegian Petroleum Directorate, for example – a new and entirely refurbished independent authority will be made up from the amalgamation of two existing entities: NAMR, that shall work in a contractual partnership and interdependence with the ultimately reshuffled Geological Institute of Romania into a Geological Survey.

This new entity must be able to:

- become an autonomous authority fully autonomous of political influences and fully responsible for the concession offering and diligent ratification;
- manage the financial resources resulted from E&P operations to improve dramatically its activity and real involvement in the technical promotion and marketing of mineral resources of the country;
- be able to implement and monitor the most modern technical research and regulations in the natural resource evaluation, exploration, and production field;
- finalize soonest, using Geological Survey competencies, the completion of the Romania geological data base started 20 years ago, converting it, once declassified, in one of its key financial assets;
- contribute to intense dissemination of basic information on Romania's mineral wealth to local and foreign companies as well as to academic institutions hopefully attracting the interest for applying new ideas and technology for access to unconventional plays and increasing production in country's aging production fields.

Coming back to the specific topic of the unconventional resources in Romania, a main additional hindrance for its development has been the use of this topic as an irresolute political instrument. For example, in 2012 during the general elections some candidates promised to ban fracking should they be elected. However, once in power the new government granted the green light for shale gas drilling in 2013, triggering a lot of unrest of the civil society and activists. And to finally complicate more the political show, in mid-2014 the Prime Minister, during his presidential campaign, was negatively assessed the gas shale resources of the country. Finally, the new elected counter candidate president has clearly mentioned late 2014, in his political program for the country, that the natural resource production royalties "must go to the local communities, possibly to the landowners not only to the state budget with an aim to help the national energy independence, rise the people prosperity and enhance citizen awareness of equal partnership with the state". A first in EU! and a change coveted for quite a lot of times in speeches and written reports by numerous industry stakeholders including the authors of this paper. During the last year, two successive governments chose to stay away from the problem leaving large expectations for this year sanctioning of a new energy strategy and concrete steps for its implementation.

3.3 Environmental Challenges

The environmental threats that might be produced by the unconventional resource production seem to be the most sensible aspect of this activity. A wave of countless rallies swept the world and disputes between myths of some and realities of others produced an entire literature crafted by the digital media discernments, technological progress, and scientific research (e.g., [43]). After a number of years of protests in North America and Europe, it appears that one of the major concerns of the civil society has been about the use of chemicals in fracking operations that would irreversibly (!) damage the surface waters and earth's environment.

The USA, the largest world producer of unconventional oil and gas, was naturally the first to meet this concern. The White House and the US Congress commissioned the Environmental Protection Agency (EPA) that undertakes a large-scale survey on the potential impacts of the hydraulic fracking. The results of the study (48) reveal, among others, that between 2011 and 2014:

- Some 25,000–30,000 wells were hydraulically fractured annually in the USA;
- 9.4 million people and 6,800 source of drinking water were located in a radius of about 1.5 km of fractured wells;
- Some 4,000–20,000 m^3L of fluids is used for 1 fractured well;
- Fluid injected could be retained in the subsurface many years, the eventually wastewater production could amount 10–100% of the initially injected fluids depending on the geological properties of plays;
- Air quality was regulated in 2012 under the Clean Air Act and through new compliance rules for reduced emission completion ("green completion") of flow-backs and new standards for toxic emissions.

EPA unequivocally found that there was no evidence for hydraulic fracturing activities producing "widespread, systematic impacts on drinking water resources in the United States" making headlines of world's most known media. Meantime, industry proposed and tested new chemicals with ingredients coming exclusively from the food industry and fracturing fluids based on LPG or CO_2 which should address most of the above exposed areas of concern.

Furthermore EPA uncompromising studies have been identified the following main areas of hydraulic fracturing potential impacts to the environment: as well:

- "Stress on surface water and ground water supplies from the withdrawal of large volumes of water used in drilling and hydraulic fracturing;
- Contamination of underground sources of drinking water and surface waters resulting from spills, faulty well construction, or by other means;

- Adverse impacts from discharges into surface waters or from disposal into underground injection wells; and
- Air pollution resulting from the release of volatile organic compounds, hazardous air pollutants, and greenhouse gases."

Most of them are minor and common to the worldwide conventional hydrocarbons drilling activities as well.

Additionally, the seismicity caused by hydraulic fracturing seems to be still a debatable and possibly a negligible issue because out of over million fractured wells in the USA there are only less than a dozen documented tremors. In Ohio, where a strong relationship between fracking and tremors was established, the maximum Richter scale magnitude recorded was 3 compared with the Fukushima 8.9 magnitude. In UK, on the Richter log scale in base 10 recordings were between 1.5 and 2.3, which is lower than a truck passing.

These being the main impacts of the fracturing itself, there are some potential impacts resulted from this industrial activity from place to place related fracking jobs, e.g., truck traffic induced low seismicity and noise, temporary visual impact of the drilling rig at night. To cope with all of these impacts, the EU Directive 2010/75/EU imposed state members to control and reduce pollution of air, water, and land produced by industrial activity. Moreover, the directive states that the "priority should be given to preventing pollution by intervening at source and ensuring prudent use and management of natural resources."

Presently, in Romania despite of formally transferring most of the EU environmental legislation, the industry and household waste management is essentially private and widely recognized as inefficient, hence highly polluting. The above described clarifications can suggest directions in the adoption of a consistent set to regulations to minimize impacts and risks of the petroleum industry activity and waste management in Romania.

NAMR must impose new or improved regulations for pre- and postfracturing controls soonest. In our sense, they should include provisions for preserving the quality of air, drinking water but also the control of well casing and cementing prior to fracturing and the "green completions." All these proposals would be in the best interest of inhabitants and their watch over perhaps are the easiest hurdle to overcome for the seasoned international companies. The unconventional resource activity can thus become an example of state monitoring and control of the environmental hazards that can result from this activity.

To end with, it appears that if all above mentioned obstacles are addressed, Romania can reasonably start exploring for testing the unconventional resource potential. Once the production of unconventional oil or gas is established it has minimal visual and ecological impact. It would boost state budget with substantial tax income, reduce unemployment, and add to communities social benefits not mentioning the positive inroads into the future energy independence of the country.

4 Conclusions

- In Romania, potential unconventional resource formations are located in both Orogenic and in Foreland sedimentary units at various depths and maturation stages;
- Unconventional assessment units were preliminary evaluated in Moesia, Scythia, Moldavian Slope, Pannonia, and Transylvania sedimentary sequences. A number of other possible plays were identified but not yet assessed for lack of data or remote forseable future of their exploration begining;
- Our inventory included unconventionals whose study is only in progress worldwide like the folded and fractured shales, clathrates, or shallow coal measures;
- The assessed resources would contain technically recoverable resources as of end 2015 are 1,000 billion m^3 of gas and 500 million bbl of crude oil;
- The full assessment of the resources can be made only after projecting some exploration drillings which shall establish, preferably after a 3D seismic acquisition over the AU, the preliminary architecture, and sedimentary facies of the rock bodies;
- The systematic geologic research of the Romanian unconventional resource basins must be included in the country's energy strategy involving both the financing of NAMR's non-exclusive studies and scientific research programs. This will eventually allow the leasing of concessions to companies with high investing potential;
- In Romania, the practice of hydraulic fracturing in conventional fields is more than 60 years old, period during which there were successfully completed hundreds of such operations. However, in the twenty-first century, the exploration of unconventionals, followed by fracturing generated large anxiety and a prompt surge in public protests; they must be addressed by politicians and industry;
- Specific regulations must be issued as soon as possible by the government bodies;
- Citizen concern must be mitigated by the transparent regulations, the monitoring of the pre- and postfracturing operations and by the public disclosure of chemicals used in the fracking fluids;
- Communities must be co-interested in oil and gas activities of the country by allocating portions of petroleum taxes to them.

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Bulgarian Shale Gas Potential Estimate

Georgi V. Georgiev

Abstract On the base of comprehensive analyses of geological structure and sedimentary basins of Bulgaria, six organic-enrich dark-shale-dominated intervals have been identified. Besides Silurian and Etropole shales (earlier determined), another four newly defined shale intervals are Lower Carboniferous, Lower Jurassic, Oligocene and Oligocene–Middle Miocene. The optimum area for each of them is outlined. The shale gas estimate is made by up-to-date methodology with consideration of the determined critical parameters. From the estimated six targets, only the Lower Carboniferous shales (in the pointed western zone) and both Jurassic shaly intervals may present moderate shale gas interest.

Keywords Critical parameters, Estimation, Methodology, Resources, Shale gas

Contents

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1 Introduction

In Europe shale gas exploration is still in its early phase. In many European countries there is a strong interest in the identification of potential shale gas objectives. However, most of the countries have no resources, or estimation of a possible resource is poor, or the estimations have a very wide range of uncertainty. Often there are serious differences in methodology, fundamental assumptions, quality and quantity of the underlying geological information. By these reasons or by dread from fracking technology and harmful environmental impact in many countries the drilling for shale gas is banned. Only in 6 countries the shale gas exploration and development is presently permitted, in other 15 countries have no present activities and not expected in near future.

Bulgaria has a moratorium on unconventional hydrocarbon exploration since 2012. In June 2011 the Bulgarian government granted Chevron with 5-year shale gas exploration permit for the 4,400-km^2 Novi Pazar block in NE Bulgaria (Fig. 1). After that the public opposition to shale gas development has increased dramatically over fear of groundwater contamination in this Dobrudja agricultural region, which is very valuable for Bulgaria. In January 2012 the government banned all shale gas exploration and production, whether or not it involves hydraulic fracturing, and withdraws a granted exploration license to Chevron [1].

In Bulgaria some shale resource assessments were reported to be underway in the period 2011–2013 [2–9]. Two shale resource targets, namely Silurian shale and Jurassic Etropole shale, have been identified and assessed by Chevron, some national institutions, and IEA/ARI (2013).

For the 4,400-km^2 Novi Pazar block in NE Bulgaria (Fig. 1) have been publically announced shale gas resources of about 0.3–1.0 Tcm (11–35 Tcf) in the Silurian–Devonian silty shale, which is up to 2 km thick, 800–2,800 m deep and has 3.5% sapropelic organic content, as it is reported in the study of Shale Gas Research Group [3].

Risked, technically recoverable shale resources in the Moesian Platform region of Bulgaria are estimated by EIA/ARI in 2013 [8, 9] to be approximately 16 Tcf (0.45 Tcm) of shale gas and 0.2 billion barrels of shale condensate.

US-based TransAtlantic Petroleum, through its subsidiary Direct Petroleum Bulgaria, holds an exploration license at the 2,300-km^2 Lovech block, later reduced in Koynare concession block (650 km^2), located in the western part of North Bulgaria (Fig. 1) [4, 5]. Many years ago the well Peshtene 5 in Lovech block flowed gas at an unstimulated rate of 15,000 m^3/d from a conventional interval in the Middle Jurassic Etropole Fm. In 2011 Direct Petroleum drilled nearby a new Peshtene 11 exploration well to core and test the Etropole shale. The well was not fracture stimulated as Bulgaria has a ban in place [4, 5, 8].

Recently an up-to-date and comprehensive study for shale gas potential at Lower Carboniferous shales, but based on limited geological information, has been accomplished [10]. The technically recoverable shale gas resources (TRR) have been estimated rather optimistic to be approximately 58 Tcf (1.66 Tcm).

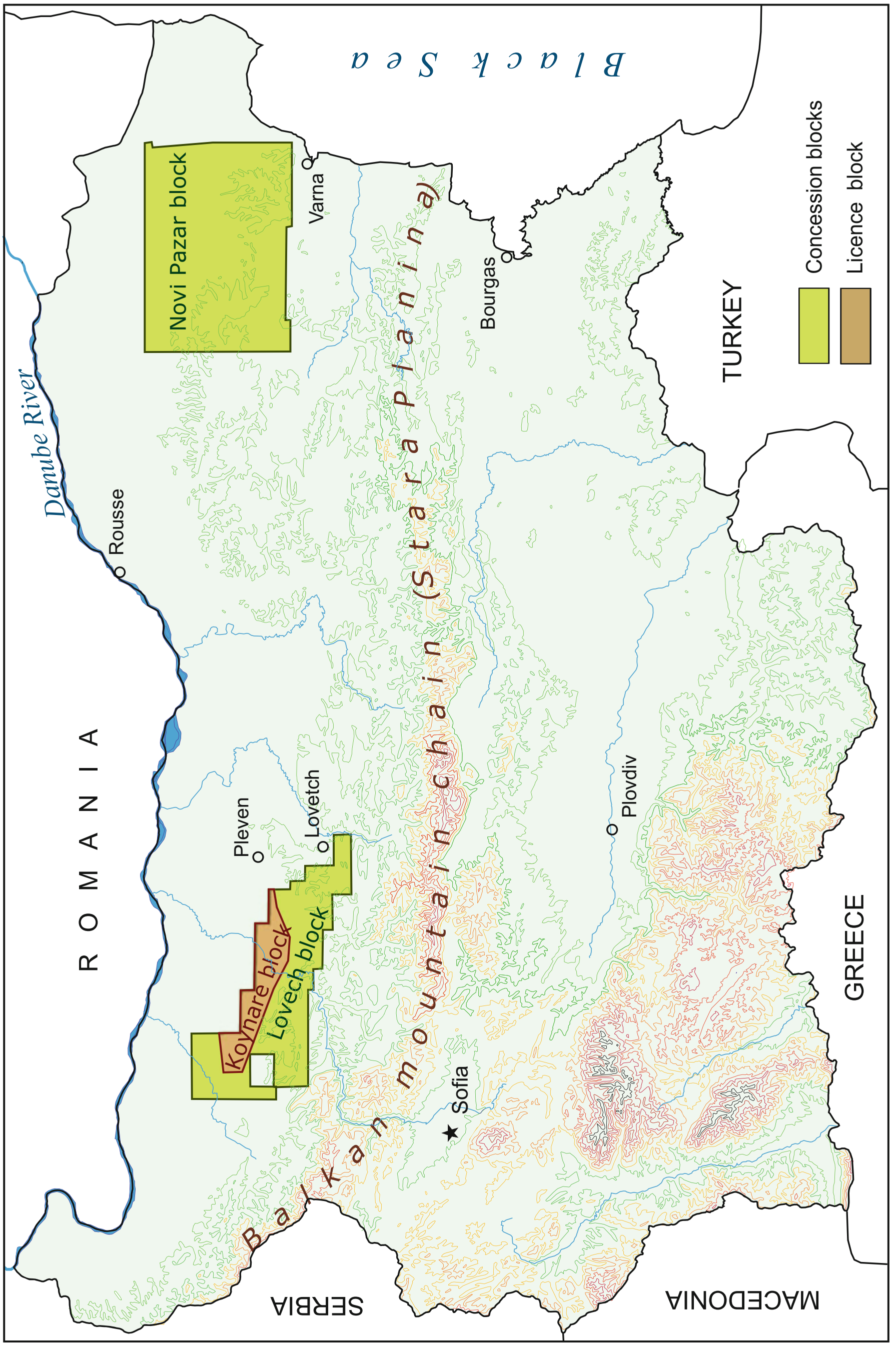


Fig. 1 General map of Bulgaria with location of some license and concession blocks

Obviously, the above mentioned assessments are based on (1) poor geological information and knowledge, (2) strongly exaggerated parameters (not proved by available geological, geophysical, and analytical data), and (3) general approaches and methodologies. They also do not comprise all possible organic-enriched dark-shale intervals in the sedimentary successions of Bulgaria. Therefore, the announced reserves are not realistic.

The present shale gas potential estimate of Bulgaria is based on (1) all available geological–geophysical data from hydrocarbon exploration, (2) analytical results from core-cutting analyses and (3) up-to-date assessment methodology [11], especially taking into consideration some additional critical parameters for shale gas resources, described below.

2 Geological Overview

Bulgaria is located on the European continental margin and covers parts of the northern periphery of the Alpine orogen and its foreland (Fig. 2).

Bulgaria has an extremely varied geology mostly developed as a result of the Alpine orogeny [12–15] and related to the Mesozoic and Cenozoic history of the northern Tethyan margin in the eastern Mediterranean region.

Two major geological domains or tectonic units are differentiated in the onshore territory of Bulgaria (Figs. 2 and 3):

- The Moesian Platform, covering the northern half of the country, dominated by thick (4–13 km) Phanerozoic sedimentary succession and block-faulted uplifts and depressions, horsts, and grabens of different ranks
- The Alpine orogenic belt that extends along the southern half of the country, dominated by igneous and metamorphic rocks and represented by mountain ranges and internal lowlands arranged in a WNW-ESE direction

The Moesian Platform forms part of the northern Peri-Tethyan shelf system. In southeastern Bulgaria, in the area of the eastern Srednogorie–Balkan zone, the southern margin of the Moesian Platform was repeatedly affected by Mesozoic rifting cycles; these were interrupted and followed by compressional events, causing strong shortening of this margin, and ultimately it is overprinting by the Alpine orogen [16].

The Moesian Platform is a foreland basin that stretches between Southern Carpathians and Balkans (Fig. 1). The Platform is overthrusted by the Balkan thrust system to the south, while the Carpathian thrust system forms the northern boundary; both are Cenozoic features related to Alpine tectonics. The orogeny of the Balkanides ceased in the Eocene, whereas the Carpathians stopped their collision in the Miocene, when the platform was finally shaped [16]. To the NE the Moesian Platform is separated from the Scythian Platform by the North Dobrogea Orogen. The easterly platform part is downwarped to the Black Sea. In contrast to

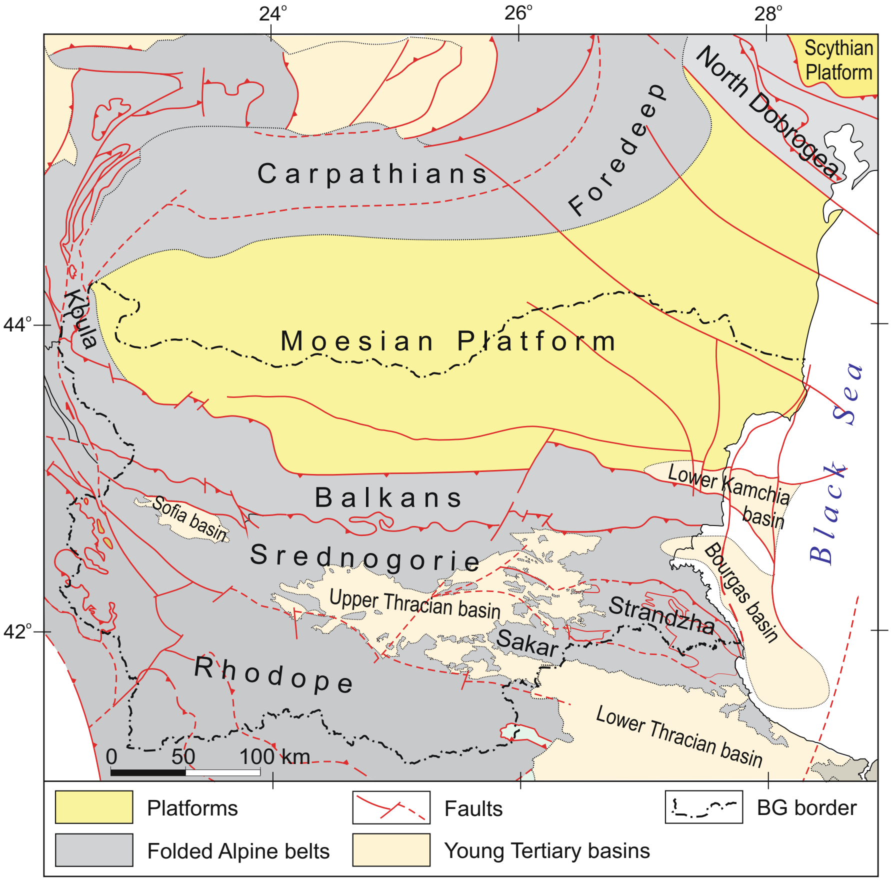


Fig. 2 Simplified regional tectonic sketch, showing Moesian Platform location (modified from Dabovski and Zagorchev [28])

surrounding thrust-fold belts, the Moesian Platform has a flat topography with typical elevation only up to 200 m above sea level. The geological boundary of the platform is well defined by the leading edge of the surrounding Alpine thrust belts.

Only the southern part of the Moesian Platform belongs to Bulgaria, much of it is situated in Romania.

The Moesian Platform is a stable continental block, comprises subhorizontal Paleozoic, Mesozoic, and Neozoic sediments with a total thickness of 4–13 km overlying a pre-Paleozoic metamorphic basement. It consists of several superimposed basins: Cambrian–Early Devonian, Middle Devonian–Permian, Triassic, Early–Middle Jurassic, Late Jurassic–Mid-Cretaceous, Late Cretaceous Paleogene, and Neogene–Quaternary. The structural pattern over the platform is

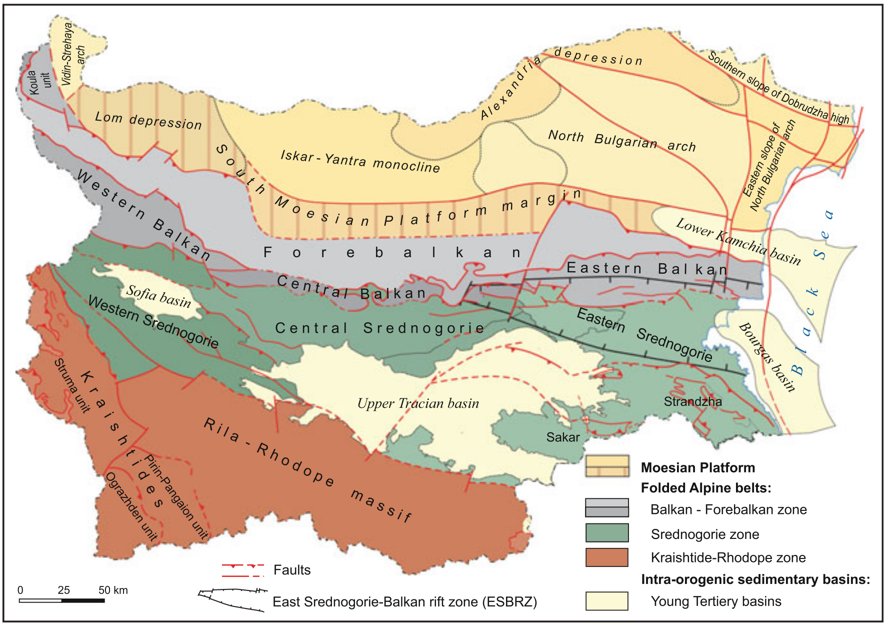


Fig. 3 Simplified tectonic sketch of Bulgaria (by Georgiev and Dabovski [43]; Dabovski et al. [15]; modified)

typical of cover deformation over reactivated basement block faults. In the southern platform, margin deformation appears to be similar to, but less intense, that in the adjacent Alpine thrusts belt: the main structures are reverse faults or not so steep to sloping thrusts and associated uplifts.

The complete Phanerozoic sedimentary succession in the Bulgarian part of the Moesian Platform thicken from about 4 km in NE Bulgaria to about 12–13 km in NW Bulgaria (Fig. 2). Major unconformities occur at the base of the Triassic, Middle Jurassic, Mid-Cretaceous, and Middle Eocene which are correlated with the main compressive events of the Alpine fold-and-thrust belt. The compression culminated toward the end of the Early Cretaceous and during the Middle Eocene [16].

The angular unconformity developed at the Triassic–Jurassic boundary is important from a tectonic and petroleum point of view [17]: below it, the Triassic successions are weakly deformed everywhere into open folds and faulted block structures, which were interpreted [18] as ramp folds above shallow-dipping thrusts in the frontal parts of a Late Triassic orogen. The overlying Jurassic, Lower and Upper Cretaceous sediments are nearly horizontal (dips of 1–4°), and normal faults, horsts and grabens dominate the structural pattern.

In the Bulgarian part of the Moesian Platform are recognized eight structural elements (Fig. 2). Some of these structures extend and have a wider development in Romania. The major tectonic units are North Bulgarian arch, Iskar–Yantra monocline and southern platform margin including Lom depression also. The most relevant are described below:

The North Bulgarian arch formed as a result of continuous Mesozoic and Cenozoic uplift (at least since Late Triassic). The arch is outlined by the Upper Jurassic–Lower Cretaceous carbonate complex, which crops out directly on the surface. The Upper Jurassic–Lower Cretaceous carbonate succession in the central arch is underlain by very thin Middle Jurassic clastic sediments that rest with angular unconformity upon weakly folded Devonian, Carboniferous and Permian rocks [19]. In the eastern arch slope, known as Varna monocline, the Upper Jurassic–Lower Cretaceous complexes dip gently to the east and southeast under a thick cover of Paleogene and Neogene deposits. Block faulting, stairs, terraces, horsts and grabens of different ranks are typical structural features of the arch.

The Lom depression comprises an almost continuous succession of Jurassic, Cretaceous and Tertiary sediments with a total thickness of over 5 km. They consist of shallow to relatively deep marine sediments that record a continuous subsidence of the western part of the Moesian Platform throughout post-Triassic Mesozoic and Cenozoic times.

The Iskar–Yantra monocline is a slope transition zone between North Bulgarian arch and Lom depression, about 140 km long. It is featured by the Upper Jurassic–Lower Cretaceous carbonate complex, which develops a wide, gentle monocline dipping to the west and south. The monocline complex covers unconformably the complex mosaic of folded, faulted, and eroded in different extent Triassic and Upper Paleozoic sediments.

The Alexandria depression developed during the Middle–Late Triassic. Only a small SE part of it spreads into NE Bulgaria.

The Southern platform margin includes the south-dipping downfaulted slope of the Moesian Platform in front of and below the thrust slices of the Alpine thrust front (Fore-Balkan). The Mesozoic section comprises a thick Triassic to Upper Cretaceous clastic and predominantly carbonated rocks; locally, the Upper Jurassic–Lower Cretaceous shallow marine sediments interfinger with deeper-marine foredeep successions. They are locally overlain by Paleogene and Neogene deposits. The structural pattern is dominated by a southward-dipping monocline, locally (and gently) deformed by north-verging thrusts.

The Lower Kamchia basin is filled up by Tertiary sediments with a total thickness of 3–5 km. Only a small part of its westernmost periphery spread onshore, whereas to the east, the basin widens, deepens, and accumulates younger sediments offshore in the Black Sea. The tectonic setting of this basin is a subject of debate: a marginal foredeep in front of the Alpine orogen, or a deep western Tertiary embayment jutting out of the Western Black Sea basin [20, 21].

Five tectonic units in the Bulgarian part of the Moesian Platform show an increase in sedimentary thickness: the Southern Moesian Platform Margin (SMPM); the Lom depression, which is considered lately as the westernmost zone of SMPM [14, 22]; the Varna monocline (eastern slope of the North Bulgarian arch); the Lower Kamchia basin; and the Alexandria depression.

The Alpine orogenic belt consists of predominantly north-verging thrust sheets and fold structures that resulted from multiphase collisions and related compressional events in the Late Triassic, Middle Jurassic, Mid-Cretaceous, Late Cretaceous, and Middle Eocene time. These were followed by crustal extension, collapse of the orogen, and development of a system of Mesozoic–Tertiary intraorogenic rift-type basins.

The Alpine orogenic system occupies in Bulgaria the area southward of the Moesian Platform. It is subdivided into three tectonic zones: the Balkanides, the Srednogorie, and the Kraishtide–Rhodope zone (Figs. 2 and 3). Cenozoic intraorogenic basins occur within the Srednogorie and Kraishtide–Rhodope zones, and its continental and shallow marine sediments extend along restricted areas.

The Balkanides form the northern external part of the Alpine orogen. To the north it overthrusts the Moesian Platform. The southern boundary with the Srednogorie zone is likewise a system of north-verging Middle Eocene reverse faults and thrusts, largely covered by Tertiary deposits of the Sub-Balkan graben system. The typical features of the Balkanides are (1) wide occurrence of Triassic and Jurassic–Lower Cretaceous platform carbonates in continuity with the Moesian Platform, (2) development of Upper Jurassic–Lower Cretaceous and Upper Cretaceous–Paleocene flysch sedimentation, (3) almost full absence of Mesozoic magmatic products, and (4) main and final compressional events toward the end of the Middle Eocene, preceded by Late Cretaceous, Mid-Cretaceous, and weak Triassic deformations.

The Balkanides are subdivided into two tectonic zones: Forebalkan and Balkan range.

The Forebalkan occupies the northern frontal part of the Balkan zone. Its principal structural elements are north-verging folds and associated reverse faults. The Mesozoic sections begin with Peri-Tethyan (Balkanide) Triassic type, followed by Lower and Middle Jurassic continental to shallow marine sediments and Upper Jurassic–Lower Cretaceous carbonate and flysch sedimentary rocks. The younger rocks are exposed mainly in the central and eastern parts of the zone. The deformation phases are synchronous with those in the Balkan unit but are much less intensive. The main compressional events are recorded in Mid-Cretaceous and Middle Eocene times. In the Forebalkan three longitudinal units are distinguished by differences in sedimentary succession and tectonic and morphologic features [23]. They are separated by transversally oriented small depressions. The Western Forebalkan is typically a post-platform orogen [24], thrusted during the Middle Eocene (Illyrian phase). In the Central Forebalkan, a very thick Upper Jurassic flysch sequence (up to 3 km) conditioned the thrust-tectonic processes in Mid-Cretaceous (Austrian phase) and Middle Eocene (Illyrian phase). In the Eastern Forebalkan, Mid-Cretaceous (Austrian phase) salt tectonics occurred, facilitated by a thick succession (above 1,000 m) of Upper Triassic evaporites [25].

The Balkan range is the easternmost Alpidic chain of SE Europe. It is strongly folded and overthrusted to the north. The sedimentary strata of this fold belt become younger toward the east: plutonic and volcanic rocks and of crystalline schists in the western part, Paleozoic in the central zone and Mesozoic-Early Tertiary in the eastern part. The Balkan fold belt is subdivided into three tectonic units: West Balkan, Central Balkan and East Balkan.

The West Balkan has a largely exposed Vendian–Cambrian greenschist basement (ophiolite, island-arc and olistostrome assemblages). It is locally overlain by sediments with large stratigraphic range: Ordovician–Eocene. The main compressional deformation events have a Late Cretaceous age. The northern boundary of the unit records Middle Eocene thrusting over the Moesian platform.

The Central Balkan unit has a pre-Mesozoic basement mainly exposed in the southern, uppermost thrust slices. These are overlain by Permian–Early Cretaceous sedimentary successions, locally overlain by Upper Cretaceous–Paleocene carbonates and Lower–Middle Eocene continental sediments. Specific feature is the presence of a thick Late Jurassic–Early Cretaceous flysch succession that was deposited in a foreland basin. This unit experienced intense Mid-Cretaceous and Middle Eocene folding and thrusting.

The East Balkan unit differs considerably from the other Balkan parts because of the large development of sedimentary sequences and a lower tectonic style [16]. It is composed mainly of Upper Cretaceous to Middle Eocene clay-carbonate and clastic flysch sequences that were deposited in a foreland basin which developed in front of the northward advancing Alpine thrust belt. These series are underlain by Lower Cretaceous, Jurassic and Triassic sediments which are exposed in the narrow Kotel belt that is associated with the frontal thrust of the East Balkan unit. Lower–Middle Jurassic black shales, exposed only in this part of the country, are typical of this belt. In some localities, they are closely associated with thick Upper Triassic flysch-like deposits. The main folding and thrusting have a Late Bathonian age, but during Middle Eocene times, the whole unit experienced renewed compressional deformations, which resulted in north-verging folding and thrusting.

The Srednogorie zone has traditionally been considered as a first-order tectonic unit based on the wide distribution of Upper Cretaceous volcano-sedimentary succession and plutonic bodies [26]. Its northern boundary with the Balkan zone is traced by north-verging Middle Eocene reverse faults and thrusts, whereas the southern boundary with the Morava–Rhodope zone is a system of faults (Maritsa fault zone) with uncertain age and relationships. The main compressional events took place toward the end of the Late Cretaceous times, followed by Middle Eocene north-verging thrusting in the northern parts of the zone. Based on tectonic relationships and specific features of the pre-Mesozoic and Mesozoic successions, three subzones are distinguished: Western Srednogorie, Central Srednogorie, and Eastern Srednogorie [27]. The specific feature for eastern Srednogorie is the presence of older Mesozoic mostly marine sediments overlapped by Late Cretaceous volcano-clastic sequences and molasses totally over 3,000 m thick.

The East Srednogorie–Balkan rift zone (ESBRZ – Fig. 3) is preserved within the thrust sheets of the eastern Srednogorie and East Balkan units. Its northern and southern border faults are deeply buried beneath the frontal thrusts of the East Balkan and Strandzha units.

The Rila–Rhodope massif and the Kraishtides Morava–Rhodope zone are situated in the internal parts of the Balkan orogenic system, south of the Srednogorie zones. This zone includes fragments of several tectonic units: Struma, Pirin–Pangaion, Ograzhden and Rila–Rhodope, each of them with relatively independent pre-Late Cretaceous history. These units are integrated into one zone [28] based on the following common features: (1) widely exposed high-grade metamorphic basement complexes typical of the internal parts of orogenic belts, (2) frequent Late Cretaceous and Tertiary intrusive bodies of different sizes, (3) development of small isolated Paleogene basins of graben type with continental and shallow marine sediments that are associated with predominantly acid and intermediate volcanic rocks, (4) main Mid-Cretaceous compressional deformations followed by Late Cretaceous–Tertiary extension and exhumation, and (5) thick continental crust (50–52 km), thinning to 34–37 km in the SE and NW directions.

In Southern Bulgaria there are numerous, small, young, intra-mountain Tertiary sedimentary basins, very restricted in area and thickness. Only Upper Thracian and Sofia basins are larger and deeper.

The Upper Thracian Tertiary sedimentary basin (Fig. 3) is 185 km long and up to 30–40 km wide. It is mostly a fault bounded graben-like depression, which developed on the central southern parts of the Srednogorie tectonic zone and partially on the northern border of the Rhodope tectonic zone. As a consequence of the aforementioned general evolution, the Upper Thracian basin has a rather complicated structure and evolution. It is filled by Eocene–Oligocene, Neogene and Quaternary deposits. During the Paleogene, the basin had a more active basement with faster and more differentiated subsident zones. During the Neogene, the structure was smoother as a result of a considerably slower rate of subsidence. The most subsiding areas are related to three small depocenters, in the total Paleogene–Neogene sedimentary thickness ranges between 1,000 and 2,000 m and outlines three small depocenters in the basin.

The Sofia basin (Fig. 3), 60 $\times$ 20 km in size, contains over 800 m Neogene (mainly Pliocene) to Quaternary clastics. Lignite and oil shale occur also in this seismically active basin.

The Bulgarian offshore covers the easternmost fragments of the Moesian Platform and Balkanides, as well as the western periphery of the Western Black Sea basin and part of the young Bourgas Tertiary basin.

The Bourgas basin is developed mainly offshore (Fig. 3). Only a very small part of its northwesternmost periphery covers onshore a very small area of 35 $\times$ 20 km. The basin developed over Upper Cretaceous volcano-clastic sequences of the Eastern Srednogorie zone [21, 22].

3 Methodological Estimation Approach

Shale gas deposits are considered unconventional gas resources that can be found in organic-enriched shale with very low permeability. These shales act at the same time as source rocks and reservoir rocks. Shale formations are typically from anoxic basins that consist of sedimentary seams with low permeability and saturated in gas. Usually, shale formations are rather heterogeneous and present a very complex stratigraphic architecture as a consequence of the numerous physical, chemical and biological processes that take place during sedimentation [33].

Technological advances related to horizontal drilling and well stimulation by hydraulic fracturing (injection into the shale a mixture of water, sand and chemicals at a high pressure) permit profitable production, moving considerable resources of unconventional gas reservoirs into the category of reserves.

Typical composition of the fracturing fluid is between 95 and 98 % water (not necessarily fresh), under 5 % of sustaining sands and less than 1 % chemical products. Until recently, companies were not making public the composition of used chemicals and this was a major reason for *concern* within the population against the use of this technique. *Other concerns related to:*

- Induced seismicity (fault movements, induced salt tectonics) and methane emissions
- Potential pollution of freshwater aquifers both from fracking fluid or methane (through usual vertical migration, or along faults, or absorption from earth surface)
- Possible radioactivity of return waters
- Damage of well construction (casing) from the very high pressures, especially on greater depths

All these aspects have to be seriously taken into account during the estimation, exploration and exploitation of shale gas resources.

The usual methodology for assessment of shale gas resources [11] are based on consideration of next main parameters:

- *Regional extent, thickness, and depth of potentially shale gas formations.* The presence of organic-enriched shales must be with large areal extent in the marine sedimentary basin (at least several thousands of square kilometers), with greater thickness, not less than 20 m, but it is as better as to be more (several scores and hundred meters) and buried depth between 1,000 and 4,500–5,000 m. Areas shallower than 1,000 m have lower reservoir pressure and thus lower driving forces for gas recovery [11]. In addition, the shallow shale formations have risks of higher water content in their natural fracture systems, piercing in not consolidated seal and vertical migration both of fracking fluid or methane. Areas deeper than 4,500–5,000 m have risks of reduced permeability, damages in well construction (casing) in conditions of very high pressures (near to 1,000 bars) and much higher drilling and development costs.

- *Organic type and richness*. Total organic content (TOC) needs to be a minimum of 2 % for generation of economical gas volumes. Organic type III produced dry gas, type II wet gas, and type I shale oil, condensate and wet gas.
- *Organic maturation*. It is needed to break down organic matter into hydrocarbons; this is what happens in mature stage of the organic matter. The main maturation indicator is Ro, which values must be between 0.65 % and 1.35 % (hydrocarbon window). For immature formations Ro is less than 0.55 % and for postmatured ones Ro is above 1.35 %).
- *Gas in place* (*absorbed and free*). It is a very important index for realized hydrocarbon generation and that the produced products (gas, condensate, oil) are in place.
- *Permeability*. Minimal values are needed for successful stimulative hydraulic fracturing and for gas production.
- *Pore pressure*. It has to be higher than normal formation pressure in depth.
- *Shale brittleness and mineralogy*. They are important indicators for successful stimulative hydraulic fracturing.

However, the estimations of shale gas resources by such methodology have a very wide range of uncertainty and often the mismatch between the hope and reality for shale gas resources is dramatic. To avoid this some *critical parameters* have to be considered additionally, which are often missed in the assessments. In our view they are with decisive meaning for a successful shale gas exploration.

Such *critical parameters* are:

- *Age of shale formation and buried depth*. The age of shale formation determines how long the generated shale gas must be saved in the source shales. As the age is older as the probability the generated shale gas to be saved is less. The younger organic-enriched shale formations (with Tertiary age) are the most promising for shale gas exploration. Concerning the buried depth in geological history and at present – as depth is less as better. Up to about 3,000–3,500 m, the geological conditions for shale gas in general are good. However, with increasing of buried depth above 3,000–3,500 m, the conditions for saving of produced shale gas rapidly get worse, what related with transformation of clay minerals from montmorillonite to hydromica. That process increases the micropore system and permeability of the shale formations.
- *Faulting, fracturing, and erosion of shale formations*. Intensive faulting and fragmentation in blocks, or strong earthquakes, could cause intensive fracturing in shale formation that make worse the conditions for shale gas, because the generated gas quickly leaves the shale sediments and migrate out of them. The same happens if the shale formation is exposed on erosion surface during the geological history as a result of inversions.
- *Presence of gas shows during the drilling*. It is an extremely important indicator for presence of gas in place. The absence means that it is not generated or it has left the source shales.
- *Effective sealing of shale formation in geological history and presently*. It is important to have an effective sealing above the source shales all time during

and after the gas generation (hydrocarbon window). Usually the clay seals worse efficiency in depth above 3,000–3,500 m, the same happens with evaporate seals in shallow depth (less than 1,200–1,000 m).

- *Maturation level of shale formation*. For dry gas prospective areas, the maturation indicator Ro is greater than 1.3–1.35 %; for wet gas and condensate prospective areas, it is between 1.0 % and 1.3 %; and for oil-prone prospective area the values are between 0.65 % and 1.0 %.

Usually, the immature and transition mature shales (Ro < 0.55–0.65 %) are considered as nonprospective for shale gas because of poor gas generation. However, if shales are enough organic enriched, they can generate bigger volumes of *biogenic gas* that forms sometimes conventional economic gas fields (as Galata gas field in Bulgaria). In such cases the immature shales may be of interest for shale gas exploration.

Postmature shale formations could save shale gas potential if they are effectively sealed, usually by salt–anhydrite deposits. Postmature stage can be indicated by clay mineralogy - the absence of montmorillonite is typical.

Improper appreciation of pointed critical parameters in the assessments of shale gas prospects can bring to dramatic mismatch between the assessed resources and received exploration results. That happens often during the last years.

4 Shale Gas Potential Estimate

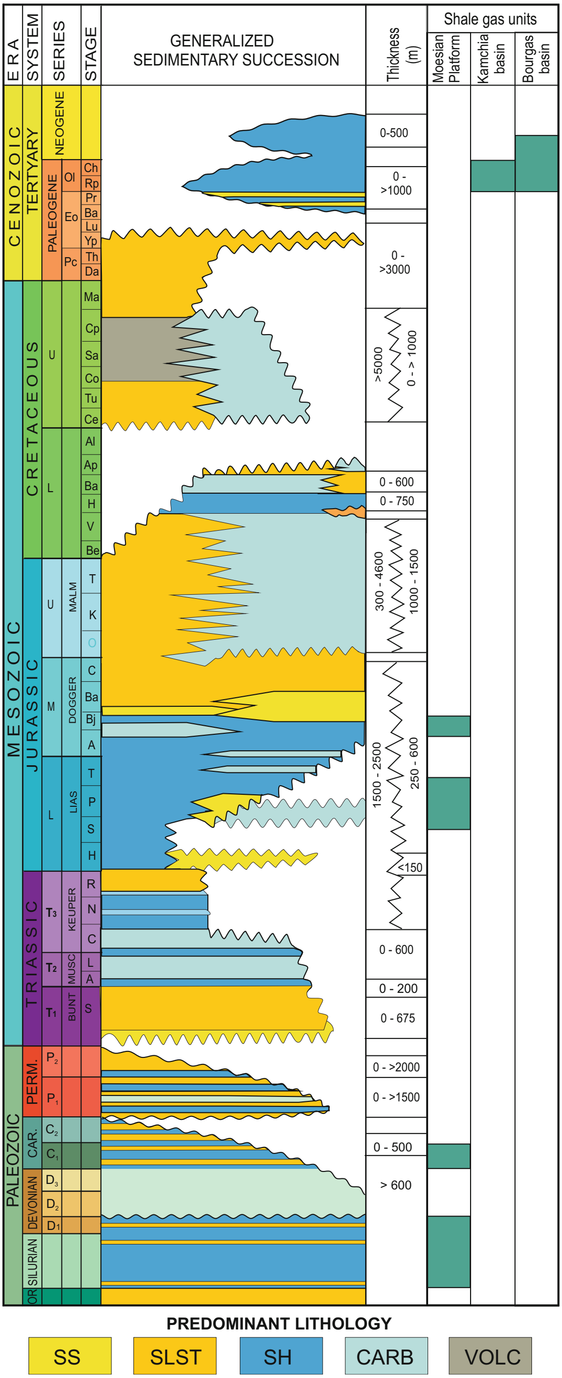
Six organic-enrich dark-shale-dominated intervals have been identified in the sedimentary successions of Bulgaria, which would be of interest for shale gas (Figs. 4 and 5). They are:

1. Silurian–Lower Devonian(?) shales
2. Lower Carboniferous shales – Trigorska and Konarska formations
3. Lower Jurassic shaly sediments – Ozirovo Formation (Bucorovo and Dolnilucovit Mbs)
4. Middle Jurassic shales – Etropole Formation (Stefanets Mb)
5. Oligocene shales – Ruslar Formation
6. Oligocene–Middle Miocene shales – Danisment and Kirazli Formations

The Middle Triassic dark shales in the Moesian Platform (Mitrovo Formation) have been ignored in this selection, because of lack of appropriate hydrocarbon generative parameters [29, 30]: average TOC – <0.5 %, gross thickness usually 40–60 m, limited area of extend.

The first four of the defined units are related to Moesian Platform basin, the fifth is spread in the Kamchia basin, and the sixth extend in the Bourgas basin (Figs. 3, 4, and 5).

Fig. 4 Schematic lithostratigraphic chart for sedimentary successions in Bulgaria with the identified potential shale gas units (based on Georgiev and Dabovski [43])



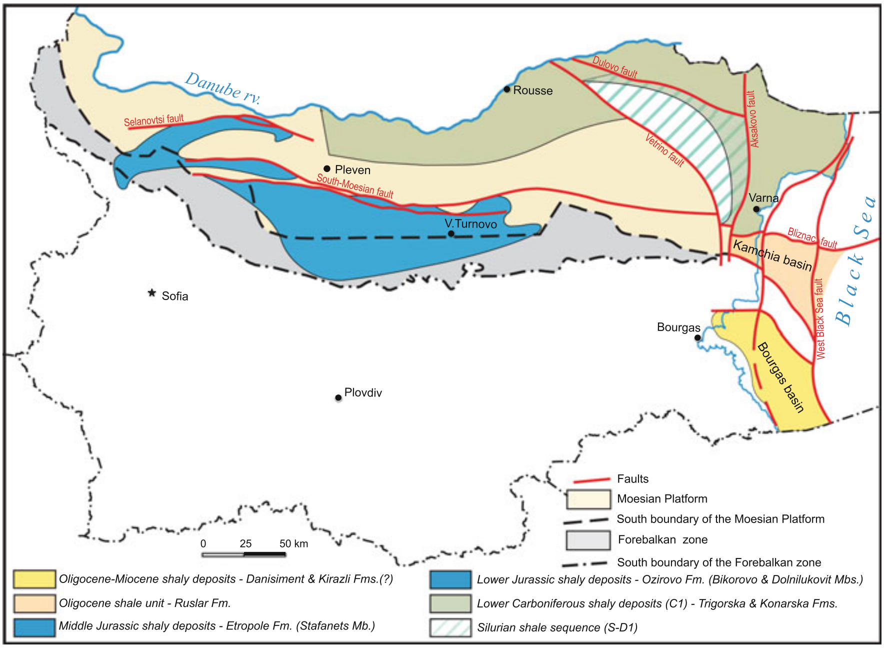


Fig. 5 Spreading of potential shale gas deposits in Bulgaria

The shale gas prospects estimate is made by up-to-date methodology [11] with taking into consideration of described above critical parameters for shale gas resources.

4.1 Silurian–Lower Devonian(?) Shales

The known extent of this shale unit related with area of 1,250 km^2 in the easternmost uplifted Vetrino block of North Bulgarian arch, bounded by Aksakovo fault to the east, by Vetrino fault to the west, and by Dulovo fault to the north (Fig. 6), [19, 31, 32]. These shales are drilled until now only by two boreholes: Vetrino 2 drilled the full section and Mihalitch 2 penetrated only the upper 700 m. Obviously, the areal spreading of Silurian shale is expected to be much larger than the outlined one. However, outside of the marked area, the buried depths are greater than 4–5 km. The drilled gross thickness is about 2,000 m, but organic-rich thickness averages about 500–550 m (gross). Silurian shales are at buried depths of 1,000 to above 3,500 m (Fig. 6), but the available data are very scant. The TOC is in the range of 0.4–3.35 % (average no more 1.5–2 %), type II–III (mainly gas prone). Porosity is usually less than 3.5–4 %. Thermal maturity of 1.3–2.2 % Ro ranges from wet to dry gas.

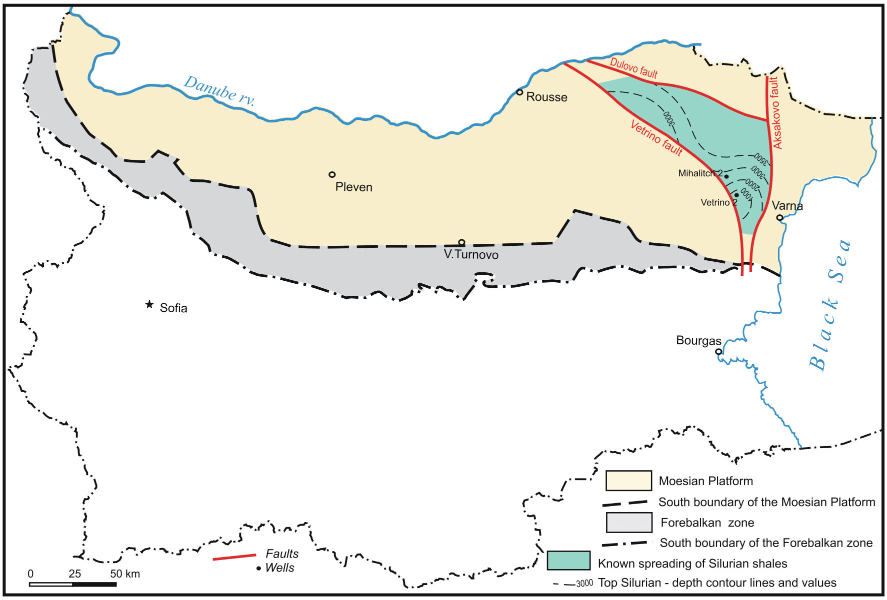


Fig. 6 Silurian shale sequence – spreading and depths

Very critical for Silurian shale gas potential is the total absence of gas presence during the drilling. The most uplifted part of North Bulgarian arch (Figs. 3, 5, 6), where are spread the reachable for drilling Silurian–Lower Devonian (?) shales, is intensively faulted and fragmented in blocks with vertical displacement of up to 2,000 m and more, as well many inversion and erosion periods took place in the geological history [19, 31, 32]. In the marked area (Fig. 6) the Lower Valanginian–Upper Jurassic carbonates crop out on the earth surface, and a very large stratigraphic gape in the sedimentary succession took place – the thin Bathonian sediments cover unconformably the Middle Devonian carbonates, that means lack of deposits from about 200-million-year-long geological period. Parts of absent sediments are eroded, and others are not deposited [19]. Before the Late Paleozoic–Early Mesozoic hiatus, the burial depths of Silurian shales were enough for development of hydrocarbon generation in them. However, during the intensive tectonics and erosional processes in Late Paleozoic–Early Mesozoic time, the generated gas (modest in volumes by TOC) had escaped the Silurian shales and *they are degasified at present*.

4.2 *Lower Carboniferous Shales: Trigorska and Konarska Formations*

Lower Carboniferous dark-to-black shale has been drilled by several wells in northern and eastern parts of NE Bulgaria (Fig. 7). The most impressive results have been received from drilled several years ago deep borehole Jernov (Fig. 7), which penetrated very thick Lower Carboniferous section (>2,400 m). Three intervals in the section are dominated by dark shales with total thickness of about 1,100 m (Fig. 7). The upper interval, about 140 m thick, related to Konarska Formation [34, 35], contains few coal seams [36]. The middle (850 m) and lower (115 m) shale intervals are related, respectively, to the upper and lower parts of Trigorska Formation [34, 35], with thickness above 2,200 m. Generally, all these shales are still poorly geochemically investigated. The recently accomplished up-to-date and comprehensive study comprises only 70–80 m from shales in Konarska Fm [10].

The Lower Carboniferous shales extend on area of 12,000 km^2, which comprises two zones separated by Vetrino fault (Fig. 7).

The western more elongated and narrow zone covers an area of about 4,000 km^2. The Lower Carboniferous thicknesses grow fast toward Danube River to 3,000 m and more (Fig. 7). Buried depths of Lower Carboniferous range between 2,700 and above 5000 m. Shale TOC values tend to be good and very good (up to 3–4 % and more). Kerogen type is II–III, maturation ranges from transition to postmature

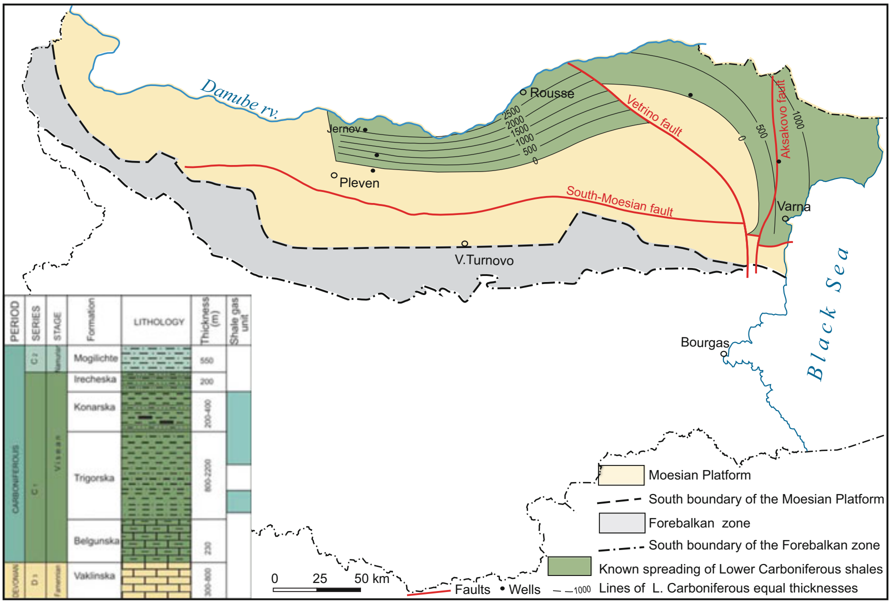


Fig. 7 Lower Carboniferous shale sequence – spreading and thicknesses

(0.6–1.9 % Ro), some anthracite inclusions have been observed [36]. In the shales there is absorbed gas with methane content of 3.5–50 % [10]. The available geological and especially geochemical data are very scant for estimation of shale gas potential. But there are moderate-to-good preconditions if the total Lower Carboniferous thicknesse is above 400–500 m. The *most critical parameters* are *the big depths and the very old age* (320–350 My).

The eastern uplifted zone (eastward of Vetrino fault) is two times larger, about 8,000 km^2 in area (Fig. 7). The Lower Carboniferous sequence occurs on shallower depth, between 850 and 3,100 m. The total and shale thicknesses are, respectively, above 1,000 and 400 m. The organic content of shales has the next parameters: TOC is up to 2–3 % (average less 2 %), kerogen tends to be type III, maturity is high – up to anthracite level [37, 38], as it is for Upper Carboniferous coals in Dobroudja field [39]. By these characteristics shale gas potential may be estimated to be fair.

However, *critical for this zone* is the absence of gas presence during the drilling, as it is also in Dobroudja coal field. The intensive faulting and fragmentation in blocks with high vertical displacement and many inversions and erosions in the geological history [19, 31, 32] have caused escaping and vertical migration of the generated gas (modest in volumes by TOC). So the Lower Carboniferous shales in this zone *are strongly degasified at present*.

4.3 Lower–Middle Jurassic Shaly Sediments

By lithological, log, and geochemical features, two potentially shale gas intervals have been detected in the Lower–Middle Jurassic sedimentary succession of Moesian Platform basin [40]. They are, respectively, related to Bucorovo and Dolnilucovit members within Ozirovo Formation and to Stefanets member within Etropole Formation [41, 42] (Fig. 8). Usually, their source features improve when the total thickness of Lower–Middle Jurassic sequence is above 350–400 m, as much as better. In addition, all oil–gas discoveries in central North Bulgaria (Dolni and Gorni Dubnik, Dolni Lucovit and others) have been chemically linked back to the Etropole and Ozirovo shaly sediments [40, 43–45]. The areal extension of the thicker Lower–Middle Jurassic sequence has been mapped by a lot of well and seismic data and cover the area of about 10,000 km^2 (Fig. 5, 8), [43].

4.3.1 Lower Jurassic Shaly Sediments: Ozirovo Formation (Bucorovo and Dolnilucovit Members)

The shaly middle part of Ozirovo Fm comprises Bucorovo member and the upper part of Dolnilucovit member. This shaly unit manifests fair-to-good hydrocarbon generative features [40]. The thicknesses vary between 200 and 500 m in the western part of the outlined area, but eastward they reduce to 40–50 m (Fig. 8). Total organic content is usually between 1 % and 2 %, rarely more. Organic type is

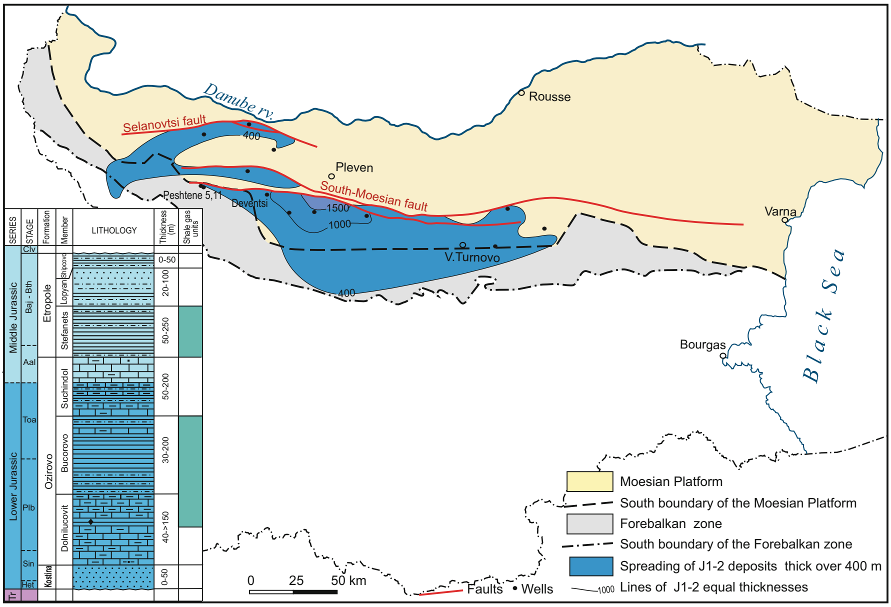


Fig. 8 Lower–Middle Jurassic stratigraphy and spreading in gross thicknesses of above 400 m

I–II, its transformation rate increases southward from peak to late maturity stage (by Ro and T_{max} values) together with fast rising of the thicknesses and burial depths from 2,600 to 4,500 m.

Borehole Devensi, drilled in the southwestern part of outlined area by Direct Petroleum Bulgaria, tested good gas-condensate flow from Dolnilucovit member [4, 8].

Critical for Ozirovo shaly sediments is the thickness, when it is less than 100 m and not so sufficient organic enriches.

4.3.2 Middle Jurassic Shales: Etropole Formation (Stefanets Member)

The organic-enriched shales in the lower portion of Etropole Formation, represented by Stefanets member, are prospective within the outlined 10,000 km^2 area in central part of Northern Bulgaria (Fig. 8). Stefanets member contains carbonate-rich (40–50 %) black shale that was deposited in a marine environment with thickness from 250 m to the southwest up to 50 m to the east. Total organic content ranges from 0.7 % to 2.95 %, kerogen type II predominate [3, 4, 8, 40, 43, 45]. The Stefanets shale generally ranges from 2,500 to above 4,250 m deep and is overpressured in much of the western zone, with an elevated pressure gradient of 0.78 psi/ft. [4, 8]. Thermal maturity falls in the oil window in the north, increasing to wet and dry gas in the south near the Balkan thrust belt (Ro 1.0–1.5 %). Porosity is assumed to be moderately high (3–4 %). Gas recovery rates also could be favorable based on the inferred brittle lithology.

The located to southwest in the area old well Peshtene 5 tasted many years ago gas-condensate flow at an unstimulated rate of 15,000 m^3/d from conventional carbonate-clastic interval within the Etropole Formation. In 2011 a new exploration well Peshtene 11 was drilled nearby by Direct Petroleum Bulgaria to core and tests the Etropole shale. This well penetrated about 350 m of Etropole shales with numerous gas that shows (C1–C3) at a depth of 3,500–3,800 m. The well was not fracture stimulated as Bulgaria has a ban in place [4, 5, 8].

The insufficient organic enriches and the big buried depths to above 4,000 m are critical for Etropole shales, because they aggravate the exploration technical and price conditions.

4.4 Oligocene Shales: Ruslar Formation

This shale unit named Ruslar Formation [46] is spread in the Kamchia basin, which extend mainly offshore in the western Black Sea (Fig. 9). However, the western basin periphery is exposed onshore and has been an oil–gas exploration target over 60 years.

Many authors considered in a long time the Kamchia depression as a post Early Eocene foredeep, based mainly on the onshore position and geometry. However, the eastern offshore prolongation shows that the basin gradually deepens and

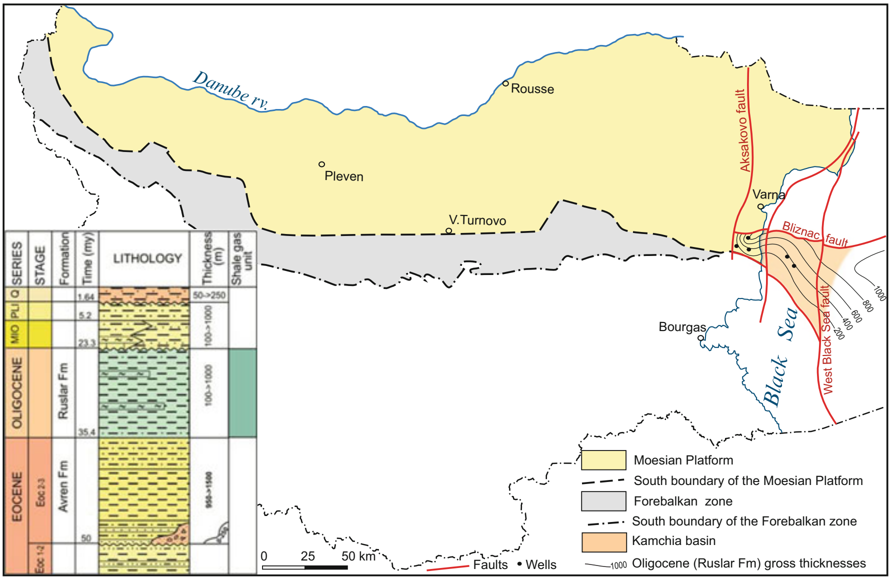


Fig. 9 Kamchia basin stratigraphy and Oligocene shale (Ruslar Fm) gross thicknesses

expands eastward and merges with the Western Black Sea basin (WBSB) floor. Hence, the Kamchia elongated basin represents westward wedging branch of the WBSB [47]. The Eocene–Oligocene sequence represents the major sedimentary fill in the western shallower periphery of the basin, while the Neogene thickness increases notably toward the WBSB floor [47]. The onshore basin area, called Kamchia depression, is small (about 200 km^2) with sedimentary feeling above the Illyrian unconformity up to 1,300–1,400 m. But to the eastward offshore, the basin gradually enlarges up to 60–70 km and deepens to 7,000 m, with area of extend near to 2,000 km^2.

The Ruslar Formation is considered to be a primary hydrocarbon source in the Kamchia basin. This sequence comprises mainly shale and claystone, occasionally grading to siltstone, with a total thickness of 100–400 m in the southern basin slope to more than 1,000–1,500 m northward to the basin axial zone and eastward to the WBSB. It is an equivalent of the Maykop Fm, which is the basic source unit in the larger Black Sea–Caspian domain.

The organic matter content is good to very good (1.4–2.8 %), dominated by amorphous kerogen type II [48]. At the drilled depth intervals, the formation is immature (0.27–0.35 % Ro) and generates only biogenic gas. However, the generated volumes form four small gas fields – Kamchia one onshore and Galata, Kavarna and Kaliakra ones offshore. Additionally, all drilled sections manifest the presence of absorbed methane in increased values.

Overall, the Ruslar shales have fair-to-good gas source potential mostly offshore. The onshore basin part and the slant drilling from the cost are good opportunity for modest shale gas exploration.

4.5 Oligocene–Middle Miocene Shales: Danisment and Kirazli Formations

This shale unit extends in the small Bourgas sedimentary basin, located mainly offshore in the southwestern zone of Black Sea [47]. Only a very small part of the northwestern basin periphery exposes onshore in the Bourgas area (Fig. 10).

The Bourgas basin has half-graben geometry, bounded to the east by the endmost Balkan unit and the Western Black Sea fault. The basin prolongation in the Turkish offshore, as well as its connection with Thrace basin to south of Strandzha, are not enough clear.

Mostly Middle–Late Eocene (Ravnets Fm), Oligocene (Danisment Fm), and Miocene (Kirazli Fm) clay deposits with many thin clastic layers and coal seams fill up this basin [47]. Seismic data indicate basin deepening toward the Bulgarian/Turkish offshore border, where the sedimentary filling reached more than 4 km. In the Bulgarian offshore zone of this basin has no drilling, but in its Turkish zone several wells were drilled.

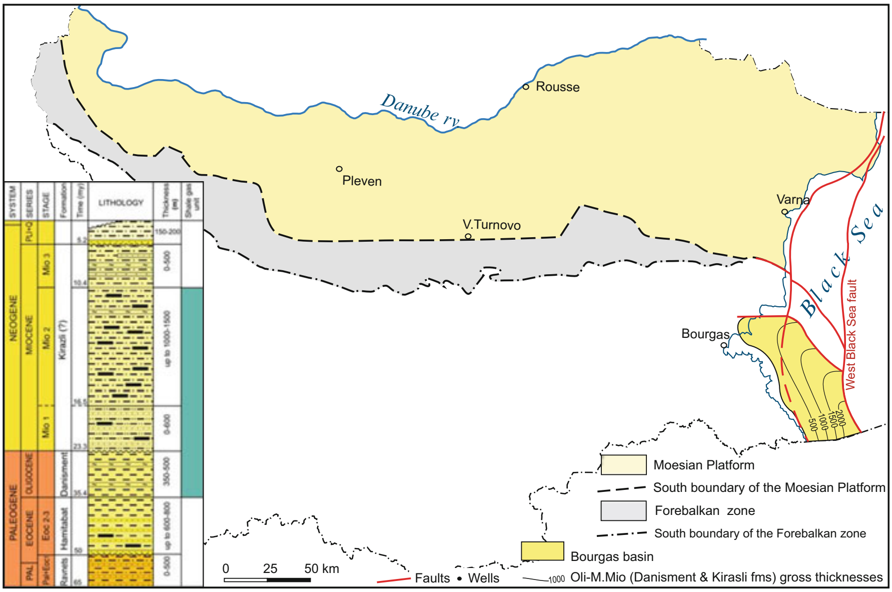


Fig. 10 Bourgas basin stratigraphy and Oligocene–Middle Miocene (Danisment and Kirazli Fms) gross thicknesses

The Oligocene–Lower–Middle Miocene shales (Danisment and Kirazly Formations) have a total thickness up to 1,500 m in basin central parts [47]. The lacustrine lignite coals and shallow to marginal marine shale, drilled in the Turkish zone, showed good source parameters – TOC in average 1.5–2 % mainly type III on immature stage (0.35 % Ro), PY up to 41.6 kg/t, and HI up to 387. The buried depths rise toward Bulgarian/Turkish border up to 2,200–3,000 m; hence, an increasing organic maturity up to early oil generation can be expected.

Overall, this source unit is mainly gas prone and generate mainly biogenic gas, which amount is expected to be significant. The drilling in Turkish offshore manifest reach saturation with absorbed and solved methane. Offshore basin location is *the most critical element* for shale gas exploration, although the main target is reachable by slant drilling from the coast.

5 Main Results and Conclusions

The accomplished shale gas estimate of Bulgaria analyze only the geological data and conditions; the environmental impact has not been subject of the study.

Some very optimistic prognoses and assessments from 2011 to 2013, including the Silurian and Etropole shales [3, 5, 7, 8, 10], have been not supported by available geological–analytical results and present-day geological conditions.

Besides Silurian and Etropole shales, another four newly defined organic-enrich and dark-shale-dominated intervals that are related to Lower Carboniferous, Lower Jurassic, Oligocene and Oligocene–Middle Miocene have been estimated.

The Silurian–Lower Devonian(?) *shales* have moderate fair generative gas abilities. However, along the Late Paleozoic–Early Mesozoic period, continued about 200 million years, the generated modest volumes gas had escaped the shales as a result of intensive tectonics, faulting and erosions. *At present they are degasified*, what is supported by total lack of gas shows during the drilling.

The Lower Carboniferous shale unit extend on large area of 12,000 km^2, separated by Vetrino fault into two differ zones. *In the western subsided zone*, the shales have moderate-to-good shale gas potential by organic peculiarities and contain absorbed methane in values of 3.5–50 %. Most critical parameters looks to be the big depths (2,700–5,500 m) and the old age (320–350 My). *In the eastern uplifted zone*, the shale organic characteristics define modest shale gas generation. However, the intensive faulting and block fragmentations, as well as the many inversions and erosions in the Late Paleozoic–Early Mesozoic geological history caused escaping and vertical migration of the generated gas.

In the Lower–Middle Jurassic succession are defined two shale gas targets: Ozirovo and Etropole formations, which have hydrocarbon source abilities, especially the lower one, only when the Lower–Middle Jurassic thickness is above 350–400 m, as much as better. All made oil–gas discoveries in central North Bulgaria genetically linked back to these two source intervals.

The Lower Jurassic shaly sediments (*Ozirovo Formation – Bucorovo and Dolnilucovit Mbs*), manifests fair-to-good hydrocarbon generative features. Thicknesses less than 100 m and not so sufficient organic enriches are critical.

The Middle Jurassic carbonate-rich marine black shales (Etropole Formation - Stefanets Mb) have good shale gas potential in the central–western zones of outlined prospective area. *Critical* are not so sufficient organic enrich and buried depth if it is above 4,000 m.

The defined two Lower Tertiary targets don't take place in traditional concepts for shale gas formations, because they are immature and are spread mainly offshore. However, in our view they have some shale gas potential, even though modest.

The Oligocene shales (*Ruslar Formation*) *are* developed in Kamchia basin mainly offshore and have a good to very good gas generative potential. The *Ruslar Formation is* equivalent of Maykop Formation. The shales are immature (0.27–0.35 % Ro) and generate biogenic gas. However, it formed four small gas fields – Kamchia onshore and Galata, Kavarna and Kaliakra offshore. All drilled sections manifest increased values of absorbed methane. *The onshore basin part and the slant drilling from the cost are good opportunity for modest shale gas exploration.*

The Oligocene–Middle Miocene shale sequence (*Danisment and Kirazli Formations*) is developed in the small Bourgas basin located mainly offshore in the SW Black Sea. The Danisment and Kirazly formations are mainly biogenic gas prone. The drilled sections in Turkish offshore manifest reach gas saturation. Most critical for shale gas exploration is offshore location, although the main target is reachable by slant drilling from the coast.

According to our estimatiom, the shale gas potential of Bulgaria is moderate to poor. From the estimated six targets for shale gas, only the Lower Carboniferous shales (in the outlined western zone) and both Jurassic shaly intervals may present moderate interest. The immature shales in Oligocene (Kamchia basin) and Miocene (Bourgas basin) are not for disparagement.

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Shale Gas Production in Moldova: Achievements and Potential

Valeriu Ostalep

Abstract No doubts that the next decade of international political processes will be influenced by the questions of energy resources. Together with climate changes, water, and oil prices, the issue of energy security, diversification, and the further development of new forms of its production will dictate the agenda of the most of the countries in the world. That's why more information, more public awareness on this topic will be helpful to understand not only the trends but can engage in broader discussions.

If these questions will remain an exclusive topic for business community and the government, without the broader implications of interested people, there is a growing risk of misunderstanding, disinformation, and manipulation. The appearance of more articles, books, and various materials on alternative fuels will help this dialog and public debate.

The shale gas is a subject very little known in Eastern Europe. Except for a limited modest number of articles, there is no information about it. Having in mind the growing importance of energy subjects for the political agenda of Russia-EU relations, the transit infrastructure in Eastern Europe, the EU Energy Treaty, this publication can be an additional helpful tool to understand the evolving trends related to energy security and the role of the shale gas in this context.

Keywords Energy policy, Moldova, Shale gas

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Contents

1 Introduction

From geopolitical perspectives, the Republic of Moldova's energy security context shows a severe vulnerability in the sector of natural gas supply. Moldova is strongly dependent on two foreign policy factors: Russia, playing the role of the sole source of natural gas, and Ukraine, through which the Russian gas is being supplied to the country. The risk of being attached to such two-element gas model fully revealed itself in 2009, when the gas dispute between Russia and Ukraine took place that resulted in the restraint of Russian gas supply to Moldova.

The "tightness" between these two energy security factors has not only a geographical but also tangible geopolitical nature. The main levers to mitigate the situation reside in finding alternative schemes and potential natural gas suppliers. The diversification of these elements could play a cutoff role in gas prices, thus, creating competition to the Russian gas. In this regard, Iran's willingness to supply natural gas to Moldova should be considered as one of the real steps toward handling foreign policy vector of the country's energy diplomacy in the Middle East. The country's energy vulnerability can also be diminished by development of the shale gas sector; the criterion of energy diversification factor could play an efficient role [1].

2 Moldova's Energy Sector Vulnerability

Nowadays, Moldova, being fully integrated into the global economic system and growingly depending on energy imports, is really interested in diversifying its energy resources. According to the provisions of the State Energy Strategy enforced until 2013, Moldova was considered to be a net importer of energy. It should be also mentioned here that oil and gas fields of the country are very modest.

In accordance with the National Action Plan draft in the field of renewable energy sources for the 2013–2020 period, Moldova is planning to secure 20% of its energy consumption from renewable energy sources (RES) by 2020. From the analysis of the situation of the country's domestic energy market, it is important to underline that the achievement of this goal by the mentioned deadline is quite problematic because of the lack of real state funds in this regard [2].

Severe deterioration of the gas pipeline networks has also a negative impact on the country's energy security. According to the State Energy Strategy, approximately 70–75% of the equipment used in the energy sector will become obsolete by 2030. In the 2001–2008 period, due to pipeline deterioration, the loss of gas amounted 7%. In 2014, the losses were 5.5% in the distribution system and 2.3% in the transportation system, respectively.

With the construction and launching of the new pipeline projects, such as the South Stream gas pipeline, Moldova could lose its status of one of the most important segments in gas transit system that is ensuring Russian energy supply to the Balkan states. This will objectively form new gas realities and would have a negative impact on the situation of Moldova. In these new circumstances the gas price for the Moldovan domestic consumers will increase again.

In today's context Moldova is an important transit country for the Russian gas supply to Romania, Bulgaria and Turkey, recently withdrawing from the route. Additionally, a part of the gas transported through Moldovan territory goes to Greece and Macedonia. In turn, the main routes Ananev (Ukraine)–Tiraspol (Dnestr Moldavian Republic, Moldova)–Izmail (Ukraine), Razdelnaya (Ukraine)–Izmail (Ukraine), and Shebelinka (Ukraine)–Dnepropetrovsk (Ukraine)–Krivoy Rog (Ukraine)–Izmail (Ukraine) and the compressor station Vulcăneşti (Moldova) are ensuring the gas transportation through the Moldovan territory to Balkan countries. Russia, in this context, is a major supplier of energy to the Balkans. According to estimates, the total volume of transit gas entering the Balkan market is 16–17 bcm [3].

3 First Results in Developing Alternative Gas Supplies

Moldova is buying from Russia 100% of its natural gas and has no alternative source of gas supply. By the beginning of 2015, Moldova is planning to ensure a regular supply of natural gas from Romania through the pipeline Iasi-Ungheni, albeit in small amounts. According to the calculations of the Moldovan authorities, it can reduce the energy dependence from Russian "blue fuel" from 100% to 95%. But only cross border residents from Ungheni district of Moldova will be able to get the "Romanian gas." The capacity of the pipeline would be of 1.5 bcm. Moreover, Romania itself does not cover its gas needs from its own sources and is importing 22–42% of the gas volume from Russia. According to Bucharest, in case of suspension of the gas supplies from Russia, the internal resources of the country won't be enough for more than 6 months [4].

In June 2014, the Government of Moldova decided to establish a state-owned enterprise, "Vestmoldtransgaz," with the registered capital of 8 million lei (about $0.574 million). The company will manage the pipeline Iasi-Ungheni and provide services related to the transportation of natural gas through this pipeline from

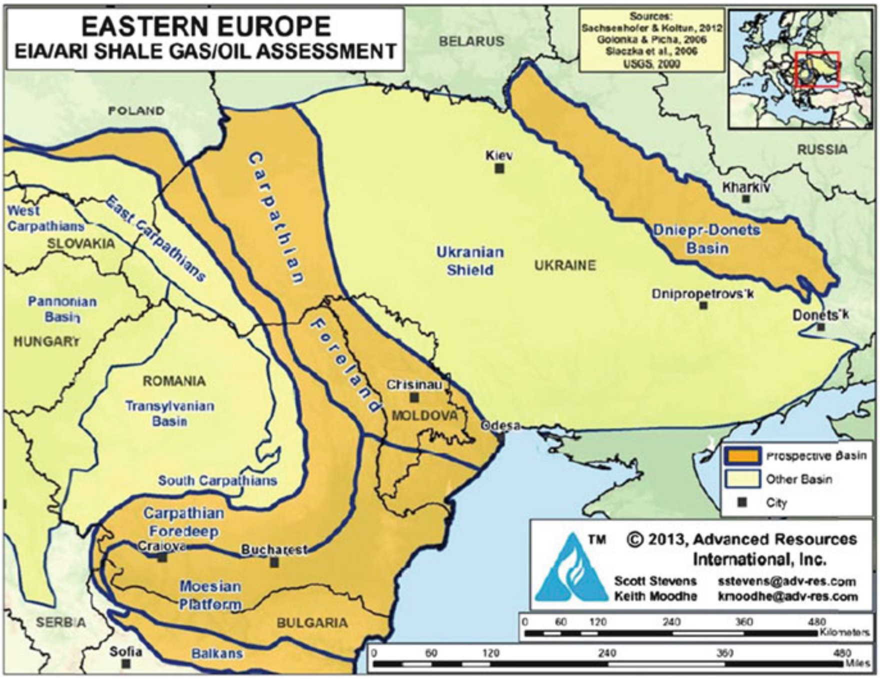

Fig. 1 EIA/ARI shale gas/oil assessment in Eastern Europe and Moldova (http://3.bp.blogspot.com/-2SIzEufgJPM/UxhulrW6iUI/AAAAAAAAAw8/SragGeYxupI/s1600/Ukrain+gas.png)

Romania to Moldova. The creation of the company was initiated by the Ministry of Economy of Moldova and is a part of the Moldovan government's actions plan ensuring "alternative sources of natural gas supply in the context of improving energy security of the country" [5].

4 Moldova Is Getting Closer to Shale Gas Production

The existence of shale gas in Romania and Ukraine, according to experts, can radically change the Moldova's energy security problems (Fig. 1). "Moldova is interested in diversification of its energy sources," said Prime Minister of Moldova, Yury Leancă, in June 2014, at the meeting held in Brussels with the European Commissioner for Energy, Gunther Oettinger [6].

The research conducted by a British company "Canyon Oil and Gas Ltd." (founded in April 2011) revealed that in the territory of Moldova, near the village Valeni, Cahul District, shale gas at a depth of 2,500 m might exist. Small deposits of oil were found in this region; the exploration of which is done by the Moldovan company "Valiexchimp."

The British company collaborated with the Ministry of Environment of Moldova in preparation of preliminary studies for the detection of shale bitumen in the concerned area.

“Canyon Oil and Gas Ltd.” already owns several sites for extraction of hydrocarbons in Moldova – an operating oil well in Valeni and two natural gas production wells in Viktorovka and Baimaclia (Cahul district) – which are located in the immediate proximity of Moldova’s border with Romania. The company took over the costs of exploration in these areas and is intending to receive 80% of the production income. The rest is belonging to the Moldovan Company “Valiexchimp Ltd.” owned by Moldovan businessman Valentin Bodisteanu who holds the license for these concessions.

The company “Valiexchimp Ltd.” is the leader in the oil and gas industry of the Republic of Moldova, and its owner Valentin Bodisteanu is the head of the professional lobbying organization of Moldovan importers and distributors of petroleum and petroleum products “Importcompetrol.” “Valiexchimp Ltd.” is the sole holder of the license for exploration and production of hydrocarbons in Moldova. Bodisteanu also owns the sole refinery in Moldova located in Comrat, which is processing crude oil produced in Valeni under the license of the same “Valiexchimp Ltd.” [7].

In the presentation of “Canyon Oil and Gas Ltd.” for potential investors, it is mentioned that the purpose of the British company is to study shale gas and oil resources of Moldova using the method of hydraulic fracturing as well as ultimate commercial production of this resource. The company has invested US $1 million into the drilling of two oil wells in the area of Valeni, Moldova. In one of them, the production started in September 2013, and the second was able to produce about 2.5 thousand barrels during February–August 2014 at a cost of $70 per barrel.

“Canyon Oil and Gas Ltd.” is expecting to double the production in Valeni by strengthening its capacities and modernizing its technological base by installation of additional upgraded equipment for drilling. The British company promised potential investors substantial income in a short period of time.

Earlier, in 2013, “Canyon Oil and Gas Ltd.” signed a cooperation agreement with the Irish company “Aminex.” This company is handling the production of natural gas in Tanzania, where the company owns two concessions. “Canyon Oil and Gas Ltd.” assets in Moldova are estimated at $2 million [8].

5 The Long Road to Hydrocarbon Resources

The first steps of Moldova in developing its commercial gas production related to early 1995 when the Government of Moldova signed a concession agreement with the company “REDECO Ltd.” (USA). The American company received then the exclusive right to oil and gas exploration in the Republic of Moldova until 2015. The field development was carried out in the south of Moldova, in the Cahul District. In the project more than $10 million were invested. Subsequently, the

Moldovan government transferred the rights to oil and gas fields exploration in the south of the country to the Moldovan company "Valiexchimp" because the former owner of these exploration rights, "REDECO Ltd.," after a series of conflicts of the American owners with the ecologists and Moldovan authorities, was reorganized being absorbed by "Valiexchimp." Its new partner became the British company "Canyon Oil and Gas Ltd." ("Moldova transferred the rights to state production of oil and gas to 'Valiexchimp' company," News Agency INTERLIC, September 19, 2007).

However, the situation changed dramatically in 2014. Director of the Moldovan company Valentin Bodisteanu denies that Moldova has shale gas resources. His company ceased cooperation with the British because they didn't have sufficient financial resources for site explorations.

A similar position is taken by the Moldovan officials. They deny their relevance to the research done by foreign company and claim that a serious analysis of the territory of the Republic of Moldova, in principle, has not been conducted. Head of the Energy Security Department in the Ministry of Economy, Vadim Cheban, declared "We don't know anything about the intentions of shale gas exploration. The Government was not given any documents in this regard. Moreover, we have no official data confirming the presence of shale gas in the territory of our country" [9].

6 Shale Gas in Moldova Requires Further Study

In the recent years, Moldovan scientists do not have a common position regarding the status and prospects of shale gas production in Moldova. A researcher from the Institute of Geology and Seismology of the Academy of Sciences of the Republic of Moldova, Vasile Nyage, said: "Last studies in this area have been conducted in 1931. In the period 1945–1972, in the territory of our country, were drilled about 700 wells with a depth of 3 km that showed signs of hydrocarbons. But with the same probability they might be empty as well. The results of samples were destroyed in the early 1990s. Shales were found at a depth of 1,700 m in Yargare of the Leova district and Rezeni of the Ialoveni district (Moldova). In the latter field were made openings in two places. Shales were found here at a depth of 1,100 m. Also work was carried out in Naslavcea, Ocnita district. At a depth of 1,200 m were found these minerals. Some shales were found on the surface. However, there wasn't any official confirmation of this fact. This kind of studies is extremely expensive: the cost of the exploration of a meter of land rises to 10,000 lei ($710). Simple calculations can reveal the total amount of financial resources necessary to conduct a study at a depth of 2,500 m."

Other Moldovan experts note that the depth of 2,500 m is not a limit for research. There might be deposits at a depth of 3,500 m, but this would substantially increase the cost not only of the initial study but also of the further development. Moldovan geophysicist, Lucian Tomescu, pointed out regarding this subject: "Moldova has a lot of natural resources, including shale gas. Shale gas might exist at a depth of 3,500 m, but its production is extremely labor-intensive. It would be a mistake for the government not to tell about the consequences of such developments. The cost of mines construction may reach $30 million in case of exploration at a depth of 5,000 m. It is regrettable that the Moldovan authorities have failed to carry out any research in this domain, since the potential of shale gas is quite important. Initiating these developments, Moldova can become independent from the energy security point of view and, accordingly, won't need Russian gas supplies."

Despite different views on the prospects of the shale gas production, many Moldovan experts are convinced that the cost of one cubic meter of shale gas in the country would amount US $ 200–300.

Ukraine's aspiration to produce shale gas and the potential existence of shale gas reserves in Moldova raised the question of coordinating efforts in the implementation of energy projects by the two countries. Former Ukrainian Energy Minister, Yuriy Boyko, reported that Ukraine has detected significant amounts of shale gas in the area adjacent to the territory of Moldova. Ukraine offered Moldova to jointly produce shale gas. Also, the Ukrainian part proposed Moldova the results of conducted studies, as well as the expertise in the field of research of this source of energy. There is also the possibility of finding shale gas near Chernivtsi, Ukraine, which is in the close proximity to the territory of the Republic of Moldova, near the cave "Emil Racovita" [10].

7 Conclusions

Due to the current mid-2014 political and economic situation in Ukraine and debts accumulated by Kiev for the consumed gas to "Gazprom," there is a huge probability of interruption in Russian gas supplies to Ukraine. "Gazprom" also made great efforts to complete the project "South Stream," which means the Russian gas will transit to Europe without passing the territory of Ukraine. This may deepen the risks that Moldova, depending on the transit through Ukraine, may be left without gas at any time.

The "shale boom" that once swept the United States and "ricocheted" the Europe has only tangentially touched the border regions of Moldova and has not brought the expected prospects of energy independence of our country. Given the fact that shale gas production is accompanied by detrimental impact on ecology and can involve a disproportionately high eventual damage to the environment, Moldova is not in a hurry to boost production of this type of hydrocarbons.

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Role of Shale Gas in the Energy Policy of Ukraine

V.G. Tsivatyi

Abstract The article analyzes the role of shale gas in the context of energy policy and security of Ukraine at the present stage. The author emphasizes general trends of the global natural gas market, as well as the prospects for shale gas production in Ukraine. Foreign policy dilemmas, challenges, achievements, and prospects in the gas production industry in Ukraine are characterized. Particular attention is paid to the political, diplomatic, and international factors of the issue researched, as well as to the environmental factor that both contributes and prevents the extraction of shale gas in present conditions on the territory of Ukraine.

Keywords Diplomacy, Energy policy, Energy security, Foreign policy, Natural gas, Shale gas, Ukraine

Contents

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1 Introduction

Ukraine belongs to the countries whose economic development is largely hampered by the lack of its own resources. In view of these circumstances during recent years, Ukraine has been increasingly concerned with energy diversification. One component of this process is the development of new deposits of fossil fuels, in particular production of unconventional gas (shale gas, coalbed methane, tight gas, etc.). That fact is attractive as the reservoirs of shale gas are formed within a large part of the territory of Ukraine, along with the extensive network of pipelines, which can ensure rapid delivery of the extracted gas. In addition, it deducts spending of significant funds for the construction of new pipelines.

Under the pressure of the increasing energy dependence of Ukraine on Russian energy supplies and constant increase in energy prices, energy intensive national economy comes up with lower production levels and stagnation of social and economic development of Ukraine. Therefore the issue of reducing the energy dependence through the formation of an efficient energy conservation programme and alternative energy development in Ukraine should be classified as strategically important, that need to be urgently tackled.

2 Energy Strategy Priorities

Today a draft document – "New Energy Strategy of Ukraine: Safety, Energy Efficiency, Competition" (07.08.2015) – has been developed in Ukraine. This system document is aimed at reforming the energy sector of Ukraine for the period up to 2020 and the formation of the long-term strategic targets of Ukraine – up to 2035 [1].

In accordance with the Ukrainian "Energy Strategy of Ukraine till 2030," the share of the renewable energy in the total energy balance of the country will be increased to 20%. The main and most effective directions of regenerative energy in Ukraine are the following: wind power, solar power, bioenergy, hydropower, geothermal energy, etc. [2].

Ukraine has considerable potential for unconventional gas (shale gas, tight sand gas, coalbed methane, etc.) (Fig. 1). Besides, Ukraine has some promising areas for the production of coalbed methane and natural gas from deepwater shelf of the Black Sea. By 2015, famous global energy companies, including Shell and Eni, have been working on projects on the extraction of unconventional gas in Ukraine at different stages.

In Ukraine, the total annual technically achievable energy potential of alternative energy sources in the recalculation on conventional fuel is about 63 million tons. The proportion of energy produced at the expense of alternative sources today is just a little over 3% [3].

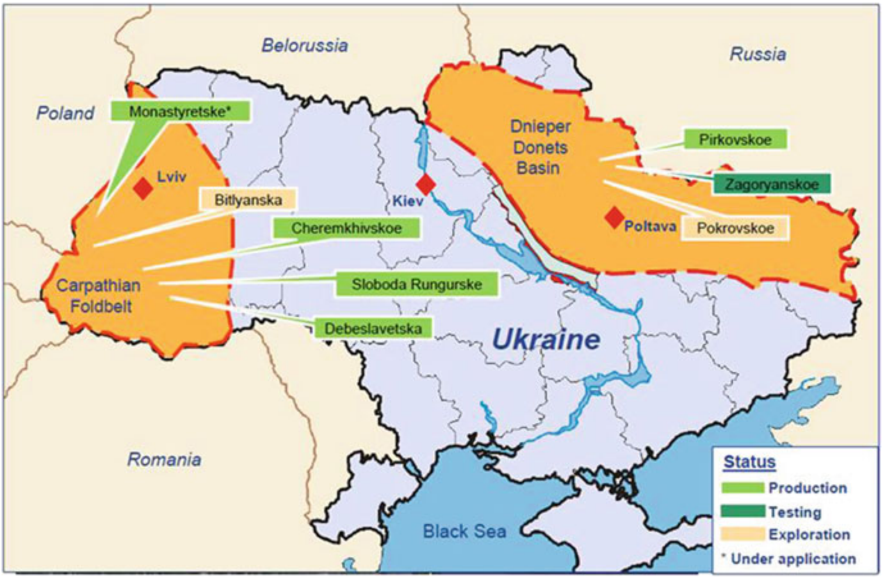

Fig. 1 Ukraine shale gas deposits (http://www.zerohedge.com/sites/default/files/images/user5/imageroot/2014/07/Dnieper%20Donetsk%20shale%20basin.jpg)

Revolutionary changes in the natural gas markets, which have been observed in world politics and diplomatic practice, have recently been associated with the beginning of a cost-effective large-scale extraction of shale gas in the USA. They significantly alter the strategic priorities of natural gas producers and consumers, and global prospects for using this energy source [4]. Undoubtedly, Ukraine, being one of the largest importers of natural gas in Europe, has also tackled an important issue of evaluating the effectiveness of shale gas production on its territory.

3 First Outcomes

Total reserves of shale gas in Ukraine are not exactly defined, but, according to preliminary estimates, they are in the range from 1.2 to 7.0 trillion m^3. Most experts agree that the reserves of shale gas in Ukraine rank the fourth in Europe after Poland, France, and Norway [5].

In 2012, Ukraine held three competitions for transactions on the product distribution for three prospective areas of possible natural gas production (Fig. 2):

- Yuzovsky (Kharkiv and Donetsk region) – the winner of the competition was the British-Dutch company Shell, which signed an agreement on transactions on the product distribution with the Government of Ukraine on January 24, 2013 for 50 years and had planned to extract shale gas;

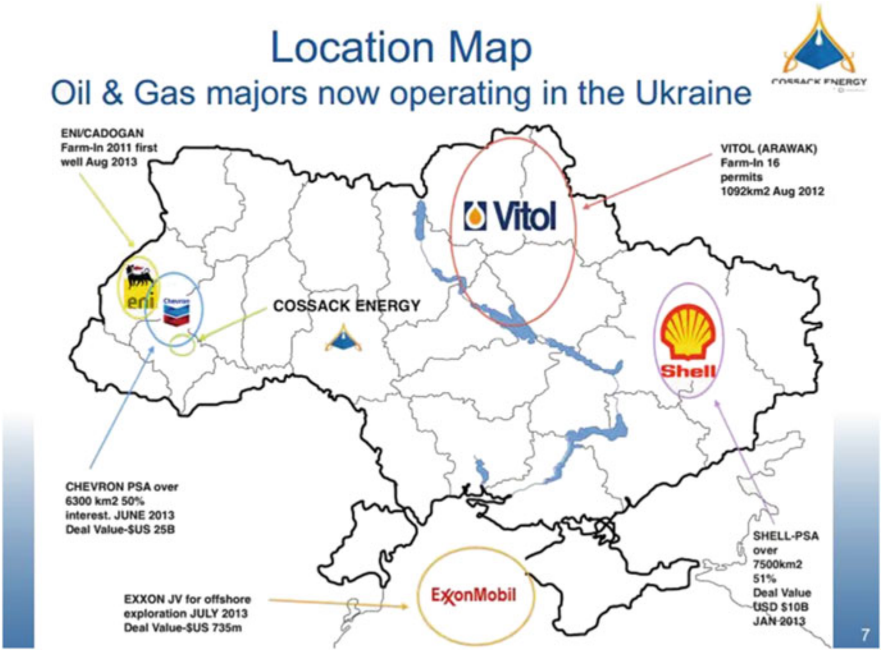

Fig. 2 Major oil/gas companies operating in the Ukraine (http://creofire.com/wp-content/uploads/2014/03/O-and-G-Majors-in-Ukraine.png)

- Olesky (Lviv and Ivano-Frankivsk region) – the winner was the American company Chevron (signing of the agreement in 2013);
- Scythian (deepwater shelf of the Black Sea) – the winner was a consortium of companies led by the US ExxonMobil (40%), Shell (35%), Austria's OMV represented by its Romanian subsidiary Petrom (15%), and National Joint Stock Company "Nadra Ukrayiny" (10%).

With a significant level of natural gas in its energy mix (more than 40%), rigid and uncompromising politics of the monopoly supplier of energy resources, and the limited capacity with respect to the geographic and economic feasibility of diversifying its sources of supply, Ukraine has to look for different options for reducing energy dependence. One of them is related to the prospects of shale gas production in Ukraine [6].

The USA intends to invest in the Ukrainian gas industry to help her stop importing gas and even to become its exporter. However, even Ukrainian experts say that the reserves of conventional gas in Ukraine are not enough, and the US companies have almost abandoned the plans to extract shale gas, or, to put it mildly, took a break for an indefinite period. Ukraine can become a gas exporter only under one condition: by serious reduction of gas consumption both by the population and by the industrial sector [7, 8].

Ukraine can increase production only through shale gas, but because of the high production costs, it will not be able to compete with conventional gas, including the Russian one. So far, Ukraine lacks a national action plan for energy efficiency: if it has been increased to the average European level, this can save annually about 34 bln m^3, which exceeds total gas consumption in Spain.

4 Target Prices of Shale Gas Production in Ukraine

The target price of shale gas in Ukraine should be discussed in particular. Trends of increasing technological complexity of production, as well as the requirements for ensuring environmental acceptability of production, increase the preliminary defined figures of pre-production cost, and probably it will make about 150–180 USD per 1,000 m^3 and the projects scale, on the contrary, can help reduce it in the long run. According to the estimates of Ukrainian and foreign experts, the cost of gas to be extracted from the Yuzovsky gas site will be 120–130 USD per 1,000 m^3. Although, it is premature to talk about the final price of production, the only thing that can be noted is that this price is less than the price of natural gas, which comes from Russia, and so, from the economic point of view, the production of shale gas in Ukraine can be fully justified [9].

Shale gas production is a long-term and quite expensive project for Ukraine. Six to nine years are necessary just to start production. Moreover, today, no one knows the actual reserves of shale gas. This requires prospecting, drilling wells. So far, there is no shale gas on the balance sheet of the Geological Service of Ukraine. Europe also cannot boast with the dynamics of shale gas production, because nothing is being developed or produced there. There were plans to start such production in Poland, but there are no sufficiently big fields found there. So now the world's shale gas production is developing dynamically in the USA, Canada, and recently in China. And only those countries can influence the global energy market [10, 11].

In March 2015, the National Joint Stock Company "Nadra Ukrayiny" has allocated 15 sites for exploratory wells for the purpose of gas production from shale. To implement long-term development plan, as a result of which the increase of fossil fuel reserves of 220 million tons of standard fuel is obtained, the company, having a limited budget funding, expects to receive $300 million from international financial institutions under the state guarantees and is actively working to attract international oil companies to participate in joint projects.

5 Prospects for Shale Gas Production in Ukraine

In 2015, the plans of many foreign companies have changed. It should be pointed out that the agreement on transactions on the product distribution in Olesky site with the corresponding local councils faces with certain difficulties. So, after the Ivano-Frankivsk Local Council had objected, Chevron agreed to disclose information about the names of the chemicals that are used for hydraulic fracturing to the state and local authorities. There are also some inconsistent aspects of transactions on the product distribution (primarily environmental).

Among major environmental threats of shale gas production, the following are emphasized: seismic risks; groundwater pollution; emissions to the atmosphere; and contamination of surface waters and soil [12].

Among the components of the environmental aggressiveness of shale gas production (fracking) towards the geological environment is a high density of wells, high pressure of hydro-crushing of layers, the possibility of artificial earthquakes, and high pressure injection of significant volumes (8,000–20,000 m^3) of technological solutions into the fracking zone [13–15].

Shale gas in Ukraine has a promising potential (up to 1.5 trillion m^3) and time equivalent of gas consumption of up to 40–50 years. However, the technology of drilling horizontal wells and hollow wells for fracking process has been implemented for 30 years in geological conditions of the USA (less depth, less pressure, etc.), but not in Ukraine [16]. In contrast, the geological environment of Olesky and Yuzovsky sites in Ukraine has a more complicated structure due to seismic (West) and tectonic (East) peculiarities that requires scientific research to adapt technology in shale gas production to the conditions in Ukraine. Besides, on the shale gas research areas there are a considerable number of people, a significant amount of developed engineering infrastructure, explored deposits of underground drinking and mineral water, and a network of environmental facilities. Now the works are carried out without adequate environmental impact assessment [17].

In general, such a process must take place within the framework of certain so-called golden rules, and become an example of transparency and completeness of the decision-making processes for the implementation of transactions on the distribution of products:

- Proper planning (maintaining a dialogue with local communities, residents, and other involved parties at all stages of field development and, first of all, before the development starts, the creation of opportunities to comment on the plans and actions of deposit developing companies, listening and providing a prompt feedback on complaints; initial evaluation of the environmental data (quality of drinking water prior to the development), and continuous monitoring of their changes; collecting and announcing operational data about the volume of water use, the volume and characteristics of wastewater, possible emissions into the atmosphere, along with a mandatory full disclosure of the information on the chemical additives and their volume, use of hydraulic fracturing, etc.; commitment that local communities receive economic benefits from mining);

- Full transparency (the choice of locations for wells, minimizing the impact on the local community, the existing land use, the environment; proper use of geologic data to select locations for drilling and hydraulic fracturing, including the assessment of the risks of deep faults and other geological effects that can lead to earthquakes, monitoring to prevent a situation when fracking can go beyond the gas field);
- Insulation of wells and prevention of leakage;
- Appropriate and rational use of water;
- Wide-scale thinking (finding opportunities for economies on scale and coordinated development of local infrastructure, which also helps to reduce the environmental impact, taking into account the overall and regional environmental effects of numerous drilling, first of all, on water use, land use, air quality, transportation, and noise environment);
- Ensuring a high level of environmental safety (the conviction that the expected level of output of unconventional gas justifies the costs; political support, relevant competence of employees, and reliable public awareness; finding the proper balance in decision-making policy in order to ensure high performance standards, promotion of innovation, and technological improvements; the belief that the plans for emergency response are reliable and correspond to the scale of risks; continuous improvement of the rules and methods of work, the provision of appropriate recognition of an independent evaluation and monitoring of environmental safety) [18–20].

The issue of shale gas production is still undefined today because of the difficult political situation. In view of these circumstances, in August 2015, the Shell company was considering to quit a joint project with the Ukrainian company "Nadra Yuzivska." Such intentions are caused by force majeure circumstances, in particular, the lack of stable sociopolitical situation in the Donbass region, which prevents the development of shale gas deposits. At the end of 2014, because of increased risks the US company Chevron refused to carry out geological exploration work at the deposits of shale gas in Ukraine. The corresponding decision on the termination of work on the shale gas sites was approved by the Board of Directors of "Chevron Ukraine BV" in July 2015.

6 Conclusions

1. Extraction of shale gas in Ukraine is possible (taking into account reserves and economic feasibility of the future price) and necessary (first of all, as a mechanism to counteract the monopoly in the natural gas supply, as well as a factor of ensuring modern high technological level of fossil fuels production, as a capital investment to state and local infrastructure and implementation of modern innovative projects).

A number of factors contribute to this: Ukraine will promptly get rid of gas dependence; the existing Ukrainian GTS (gas-transporting system) can quickly deliver gas to Europe; and the situation in the country is so poor that no one will even remember that the technology of hydraulic fracturing (HF) is not entirely harmless to the environment and requires a lot of water.

2. The absolute priority for implementation of shale gas production in Ukraine should be observance of the "golden rules" of shale gas production, which include: planning issues; full transparency of the implemented projects; participation of local communities in important decision-making; constant monitoring and control of environmental impact, including, independent assessment; adoption of regulations to ensure high standards; encouraging innovation and technological progress, despite the possible rise of the cost of the implemented projects, etc.
3. Environmental constraints for shale gas production projects do exist, but modern technological level of production enables us to reduce them to a minimum. However, environmental NGOs constantly study the issue and advocate implementation of best international practices, as well as coordinating the efforts of public authorities to prevent effectively the threats to environmental security.
4. Despite the undeniable positive aspects of implementation of the projects of shale gas production, it is appropriate to restrict the conclusion of new agreements for analysing positive and negative experience.
5. It is urgent to identify other opportunities to limit gas dependence primarily by a significant increase in energy efficiency, increasing the share of coal in the energy balance of Ukraine along with the implementation of modern technologies and compliance with high environmental standards, the development of other nontraditional or alternative sources of energy (regenerative energy from the sun, wind, geothermal, biomass energy), etc.
6. Only after the analysis of the material from experimental landfills, competent and reliable conclusions regarding the future development of shale gas production in Ukraine can be drawn, in particular considering the volume of its stock.
7. Energy issues in today's polycentric world play an important role in determining foreign policy strategies in relations between states, including the energy sector. One of the main means of implementation of such policies is the energy diplomacy. Geopolitics at the same time plays the role of coordinator of the areas of diplomatic means and methods in order to establish mutually beneficial cooperation between the states in the energy sphere. Ukraine should create an effective energy diplomacy with the aim of maintaining the energy policy of Ukraine as an independent functional area of foreign policy and diplomatic activities of the state.

In contemporary energy diplomacy, important sets of relationships should be defined: between consuming states; between resource-producing states; between the producers; between groups of resource-producing states and consuming states in the framework of international energy organizations; between producing and consuming states; and between importing and exporting states and transit states as well.

Currently, a system of world energy policy and diplomacy at global, regional, intergovernmental, and corporate levels has been set. Organizational and legal basis of bilateral and multilateral diplomacy are being formed. Ukraine takes an active part in the political and diplomatic processes of their formation.

In order to strengthen Ukraine's position in global and regional division of labor, to maintain sustainable development of its national economy and energy sector, it is necessary to carry out not only a series of unpopular but uncontested changes in the organization of the functioning of the energy sector, but also the implementation of urgent reforms in the political, social, and economic spheres. The transformation of energy sector of Ukraine should begin with a radical revision of the policy of energy efficiency and the development of its own highly efficient energy diplomacy.

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Shale Gas in Russia: New Outlines of the Energy Policy

Sergey S. Zhiltsov

Abstract The interest to the shale gas in Russia has grown after the USA increased significantly the production of this hydrocarbon. However, this interest does not go beyond discussions at the expert level, and mention of this issue in some documents and declarations of politicians. No haste to organize the industrial shale gas production can be attributed to the lack of accurate data on the shale gas reserves in the territory of Russia, high production costs, and high environmental risks. And one more factor – lack of technologies.

Keywords Production, Reserves, Russia, Shale gas, Technology

Contents

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1 Introduction

The extraction of hydrocarbons from shales started in Russia in the nineteenth century. However, for a long time it was mostly the shale oil production that was initiated in the mid-nineteenth century and in small quantities. The shale oil was used largely as a fuel and in manufacture of ichthyol. The industrial scale development of shales began in 1919 in the Kashpirsky mines in the Samara province.

In the Soviet time, shale oil was extracted in Estonia that was a part of the Soviet Union, in the Leningrad Region, and nearby Syzran in the Samara region [1].

The US efforts on application of the fracturing technology to increase the oil and gas output were not neglected. In the 1950s, the first developments in this area were made in the USSR, too. In 1953–1955, Soviet scientists Yury Zheltov and Grigory Barenblatt headed by Academician Sergey Khristianovich developed the theory of formation and propagation of fractures as a result of hydraulic fracking. This theory influenced further production of hydrocarbons from unconventional sources. Based on the theoretical developments of the scientists, the hydraulic fracturing of a coal formation in one of the Donbass mines was conducted in 1954 [2].

The theory of shale gas production developed by S. A. Christianovich was successfully applied in the 1970s–1980s in the territory of the USSR. However, the shale gas extraction was not large scale. These methods were mostly used to develop the low capacity oil and gas fields [3].

2 Discussions of the Shale Gas Production

Regardless of rather vague perspectives of shale gas production in many world countries, Russia started gradually to discuss this issue. It should be said that for several years the relation to the shale gas in Russia has changed quite perceptibly: from complete negation to stirred up interest to production of this hydrocarbon.

The interest to the shale gas was provoked, to a great extent, by the information about successes in shale gas production in the USA which gave rise to speculations about the coming redistribution of the global gas market. However, the Russian experts in this industry believe that the nearest decades will not witness the radical changes in the oil and gas market. Many Russian experts thought that the growing production of shale gas would not change the situation in the gas market of Europe as this growth was supported by state financing [4].

However, in Russia the situation with the shale gas production in the USA was now in the focus of attention and the policy of European countries in this sector was followed more closely. In recent years, various events have been held in Russia with participation of politicians and experts who touched upon the shale gas issues in their speeches. Thus, in March 2010 the RF State Duma organized the round-the-table meeting for discussing the topic “Perspectives of Shale Gas Development.” Among the participants of this meeting, there were representatives of the leading research institutions, including RAS, as well as the representatives of the oil and gas companies. At this meeting, it was noted that Russia had the sufficient natural gas reserves; however, their development requires significant investments. Besides, it was stressed that the shale gas development was meaningful in the vicinity of consumers, in the regions with developed infrastructure and having no single gas supply system.

In April 2010, Yury Trutnev, the then Minister of Natural Resources and Ecology of Russia, said that the growing production of shale gas was a serious problem for Gazprom and Russia, in general [5]. This was the first declaration of such kind on the part of a member of the Russian government.

Regardless of the shale gas production boom in the USA, Russia only discussed the prospects of development of the shale gas plays. Oil and gas companies were not in a hurry to start shale gas production stressing specific features of this undertaking: relatively low yields and their sharp decline already in the first years of production, great volumes of prospecting drilling, permanent search for new sites for drilling, and great investments for project implementation. These factors determine the role of shale gas as a local hydrocarbon source.

At the same time, many Russian experts agreed that it was necessary to evaluate the shale gas potential of Russia, to study the advanced technologies of shale gas production and to assess perspectives of their application. According to EIA data for 2013, the proven shale gas reserves in Russia made 8 tcm, or 20% of the current gas reserves [6]. Taking into consideration the enormous natural gas reserves in Russia and low cost of their production, it was concluded that shale gas production has not been so far cost effective. Moreover, the prospects of shale gas production in Russia pose many questions and, primarily, this is connected with the fact that no geological surveys of shales have been conducted in Russia. Accordingly, there is no even rough information about the shale gas reserves in Russia.

3 State Policy: New Benchmarks

Regardless of restrained assessments of perspectives of the shale gas production by the oil and gas companies and some experts, the attitude to this business at the state level has been changing gradually. In late 2010, Dmitry Medvedev, the then RF President, ordered to develop the state program of unconventional hydrocarbon production, including shale gas.

In 2011, the Committee for Energy of the State Duma recommended the government to conduct assessment of the shale gas potential of Russia, to study the most advanced technologies of its production and to appraise the possibilities and prospects of their application in Russia. Moreover, they stressed the need of detailed study of the effect of development of the shale industry in the USA and its likely appearance in European countries and China on the current and future export of gas from Russia [7].

Witnessing the growing attention in Europe to the issues of shale gas, the discussions of shale gas problems have been extending in Russia, too. The key topic here is the cost of shale gas production at which the Russian gas will remain competitive. It was assumed that at the shale gas cost of US$270–280 per 1,000 m^3 in Europe the Russian gas remained competitive.

In general, the "shale revolution" was most likely a motive to stress the importance of further development of pipeline projects. Russia did its best to prove their necessity emphasizing the role of the existing and would-be projects for improving the energy security of Europe. On the other hand, the opponents focused on the growing role of shale gas that would reduce significantly the need to construct new pipelines for the Russian gas.

The main problem faced by Gazprom is the depletion of gas fields and acute need in large investments for the development of new areas: gas fields in Western Siberia have been worked out for more than 50%, while the share of not easily recoverable reserves exceeds 60% and continues growing.

The US successes pushed investigations with a view to find places for this resource production in other world regions, in particular, in Europe and Asia. At the same time, shale gas projects have some specific features in terms of technology and economics, among which there are great volumes of prospecting drilling, sharp decline of well yields already in the first years of production, the need for permanent moving to new production sites, and serious environmental risks. In addition, the cost of the shale gas production in the USA is high and exceeds the cost of traditional gas production in other world regions, including in new fields in Russia. These factors assign to shale gas the role of a local hydrocarbon resource called to offset the reduced production (or absence) of traditional gas in regional markets. Consequently, the new principles of price formation should be suggested to influence the exporters, including, primarily, Russia. However, Gazprom is going so far to continue its monitoring of the shale gas industry development [8].

Gazprom possesses its own technologies for unconventional gas production and applies them in recovery of coal methane in Kuzbass. At the same time, in order to preserve its status of the major gas exporter to Europe, Russia will have to take into consideration the tendencies underway in the European gas market [9]. This factor explains the growing attention in Russia to the shale gas issue.

4 Russia Makes First Steps to the Shale Gas Production

Beginning from 2012, in view of the rapid growth of the shale gas production in the USA, Russia started discussing the prospects of shale play development. The importance of shale gas was stressed by the Russian President. Speaking in the RF State Duma in April 2012 with the report of the government, V. Putin said that the country should be ready for reshaping of the hydrocarbon market due to improvement of the technologies of shale gas extraction. Moreover, the Russian President noted that the new wave of technological changes is coming and in recent time many efforts have been taken in the USA for improvement of the shale gas production technologies [10].

At the same time, the RF Ministry of Economic Development presented Scenarios of the Long-Term Forecast of the Social and Economic Development of the Russian Federation Till 2030 [11]. This document outlined the ranges of likely production of shale gas that by 2030 could increase from 60 to 128 bcm. And this is in spite of the fact that no geological surveys have been conducted in Russia, the absence of data on the shale gas reserves, appropriate equipment, technologies, and personnel. Moreover, the Governmental Report on the State and Use of the Mineral Resources of the Russian Federation in 2010 mentioned that no shale gas plays had been found in Russia [12].

In August, the RF Ministry of Economic Development drew attention to the potential threat for the country if the USA would continue extension of the shale gas production. In October of the same year, RF President V. Putin at the government meeting devoted to the fuel and energy complex ordered Gazprom to study the consequences of the "shale revolution" in preparing the gas export strategy. In November, the RF Ministry of Energy approached the government with the proposal to start production of shale oil and gas. In addition, the ministry believed that the technologies of shale hydrocarbon extraction should be developed in Russia on the special testing site and small plays (http://www.finmarket.ru/nws/hotnews.asp?id=3137136).

Later in the same year, the RF Chamber of Commerce and Industry met with the Russian Union of Oil and Gas Industry and the Russian gas community to discuss the issues related to prospects of shale gas production. According to President of the Russian Union of Oil and Gas Industry Gennady Shmal [13], the reserves of shale gas are roughly estimated at 25 tcm and its production by 2030 may reach 3 bcm.

In 2013, Russia continued discussion of the shale gas issue. This topic was mentioned in some documents adopted by the government. Thus, according to Ordinance No. 436-p of the RF government of March 2013 "On Approval of the RF State Program on Reproduction and Use of Natural Resources", it was planned to conduct assessment of the resources and reserves of shale gas, gas hydrates, and coal methane, first of all, in the regions with oil and gas deficit. The formulation of such goal was connected with the growing significance of the "shale" factor in the world gas production. The requirement to develop shale plays was stressed once more in May 2013 at the collegium meeting of the RF Ministry of Energy where the participants spoke about the need to develop not easily recoverable reserves.

In April 2013, Vladimir Putin noted that Gazprom had not missed the "shale revolution" and drew attention to some aspects of this problem. First, the Russian President pointed out that the cost of gas extracted from shales was much higher than the cost of traditional gas production. Second, Russia possessed sufficient traditional gas fields. Third, as V. Putin remarked, the extraction of shale gas and oil involved enormous environmental risks. And here the Russian President stressed that Russia did not discard completely the shale gas production [14]. A year later, in April 2014, the Russian President once more stressed that the shale gas production was very costly and there was a real threat that many projects for development of shale gas could be unprofitable [15].

5 Russia in Search of Extraction Technologies

In 2014–2015, the shale gas issue was discussed more than once at the expert level and in Russian governmental structures. The key idea of numerous discussions and publications was the development of own technologies of shale hydrocarbon extraction and measures capable to mitigate the likely effects of the factor of "shale revolution." Moreover, it can be assumed that one of the constraints for development of the shale gas production in Russia is precisely the lack of required technologies.

The Russian authorities and companies focused their attention on technologies. From 2011, such Russian companies as Rosneft, Gazpromneft, Tatneft, and others started using some elements of the shale technologies in development of oil fields. For this purpose, Russia invited foreign oil and gas companies to establish joint ventures with them; primarily, these were such companies as Shell, Total, and ExxonMobil. Moreover, in exchange for access of ExxonMobil to explorations in the RF Arctic waters, the Russian Rosneft obtained a share in the projects of ExxonMobil, one of the largest US companies, in North America, including the shale oil field Cardium in Alberta. In this way, Russia was seeking to master the directional drilling technologies and hydraulic fracking that could be applied later on in development of its own fields [16].

In the 2011–2014 timeframe, the number of wells drilled with the fracking technology has increased threefold in Russia. They included not only wells drilled for shale gas extraction, but also wells drilled in oil fields applying the elements of fracking.

As a result of sanctions imposed against Russia in 2014 by Western countries, the cooperation in the oil and gas area has shrank drastically. And the more so as the sanctions affected, primarily, the activities of Western companies that could transfer technologies used in development of shale plays. Consequently, the just started interaction in the oil and gas field of the Russian companies with foreign oil and gas giants has been stopped [17].

The future of the Russian gas, and its competitiveness in the world energy market will depend, to a great extent, on how much the Russian scientists and specialists will manage to progress in development of technologies ensuring considerable reduction of production costs along the whole chain – extraction, preparation, transportation, and distribution of gas and in addressing the technological problems [18].

In general, it can be said that in Russia the discussion of the shale hydrocarbon production has not transformed into decision-making called to reduce the vulnerability of the gas sector in the Russian economy. As before, the pipeline transport is in the focus of attention. Such disregard of new extraction technologies enhances the risk of negative influence on Russia of the "shale revolution" whose results will affect strongly the formation of the Russian gas policy. Finally, it can be said that Russia and its gas sector are threatened not by the "shale revolution" proper, but its lag in technology, and its non-susceptibility to producing new technologies of the last generation [19].

6 Conclusions

The Russian experts and governmental structures being in charge of the fuel and energy complex are now facing a very serious challenge. It is necessary to assess objectively the changes underway in the global market connected, among other things, with the shale gas production. Meantime, Russia has no so far consolidated position towards shale gas and, which is more important, no clear-cut strategy of actions. The report of the experts from the Centre for Macroeconomic Research of Sberbank underlined that already in 4–5 years the Russian gas exporters will face a sharp growth of competition in all countries being potential importers. Therefore, according to expert estimates, it is time to think about improvement of efficiency of the gas industry and its likely restructuring [20].

The “shale revolution” may lead to serious geopolitical changes. In terms of the Russian economic and political interests, the greatest risks are connected with the shale gas production in Europe as the European countries consider the shale gas as one of the alternatives to the natural gas from Russia.

In recent years, Russia has faced the intensifying competition in the European market. Growth of the liquefied gas supply and drop of demand for gas force Gazprom to adjust the cost of gas supplied to the European market. The competition in the European market is influenced significantly by the USA showing a sustainable growth of the shale gas whose supply to the gas market of Europe is only a matter of time.

If we proceed from projections of the shale gas production in Europe, it becomes clear that Russian gas will remain for long one of the main sources of hydrocarbons for European countries. The key issue will be the cost at which Europe will purchase Russian gas. However, by estimates of the RAS Energy Research Institute, if the “shale revolution” continues, then by 2040 the Russian export will be cut by 70 bcm which will result in the reduction of the Russia’s share in the European market [21].

In the foreseeable future, there are some factors that will affect Gazprom, among which there are the supply of liquefied natural gas and application of energy saving technologies in Europe. Moreover, in recent decade Russia has faced the problem of technologically lagging behind which creates obstacles for implementation of projects of hydrocarbon production in not easily accessible places, in particular, in the Arctic region with its very complicated geological and climatic conditions requiring principally new technological solutions [22].

In Russia, the shale gas plays are not surveyed because so far they are considered unfeasible remembering the enormous traditional gas resources and reserves [23]. In late 2014, Gazprom took into consideration the information about the results of the shale gas production in different world countries. The company noted that currently the shale gas production in Russia was still viewed as unfeasible explaining this by the enormous reserves of traditional natural gas whose production cost was much lower than the expected cost of shale gas extraction and the negative environmental impact of the shale gas production [24].

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Evaluation of the Shale Gas Potential in Kazakhstan

Lidiya Parkhomchik and Bela Syrlybayeva

Abstract The article considers the primary evaluation of the shale gas resource potential in Kazakhstan and outlines the most problematic issues for the large-scale shale gas production across the state. The authors pay special attention to the national strategy of the Kazakhstan government in the sphere of the unconventional energy production and define the likely technological and environmental problems for the shale gas extraction. It is also stressed in this chapter that application of the fracking technologies could cause both positive and negative effects on the economy of Kazakhstan. Therefore, further steps in this direction should be based on the meaningful and comprehensive geological data regarding the shale gas potential.

Keywords Energy strategy, Shale gas production, Shale gas prospective deposits, Unconventional energy sources

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1 Introduction

Nowadays, the world energy has entered a new phase of the technology life cycle. The emergence of revolutionary technologies and renewal of industrial infrastructure permitted to combine horizontal drilling with multistage hydraulic fracturing and proppant injection. As a result, it became possible to start the commercial production of unconventional hydrocarbons, such as shale gas. It should be noted that the very first attempts to extract unconventional gas were made in the USA in the 1980s. The first vertical shallow wells (150–750 m deep) had been drilled in the northeast of Texas. Using the hydraulic stimulation technology, the companies started extraction of gas from carboniferous shale formations. [1] However, the large-scale commercial production of shale gas began only in 2002, after the US Devon Energy pioneered a combination of directional drilling and multistage hydraulic fracturing. Over the past decade since the technological breakthrough in the development of the shale gas production, the USA became the absolute leader in the extraction of unconventional fuel and, apparently, it will hold its leadership in the medium-term perspective.

Inspired by the example of the USA, the countries with the highest natural gas consumption began to search for shale gas plays in their own territories. With time on the surveys of the gas-bearing shales have been expanding providing access to a growing number of unconventional hydrocarbon plays.

According to the second report of the Energy Information Agency (EIA) at the US Department of Energy entitled "World Shale Gas and Shale Oil Resource Assessment,"[1] which was published in July, 2013, the world recoverable reserves of the identified type of fuel are estimated at about 7,299 trillion cubic feet of shale gas and 345 billion barrels of tight oil. Comparing with the data of the first EIA report on the similar topic, the world recoverable shale gas reserves increased by 9.3%, while the volume of tight oil deposits increased 10.7 times [2].

It should be noted that by extending the coverage of the shale gas resource assessment, the US government pursued a quite pragmatic goal, namely to evaluate the possibility of the US fracturing technologies transfer to other countries, as well as to increase the volume of the US liquefied natural gas supply to the potential markets. However, the EIA report stated that ongoing studies were still far from being able to give the public a full picture on shale gas and tight oil world reserves. This was primarily due to the virtual absence of information on the amount of deposits of the identified type of energy sources in key energy producing regions like Middle East, Central Africa, Kazakhstan, etc. [3].

The lack of statistical data on total volume of unconventional hydrocarbons in the designated areas, which can be easily seen in Fig. 1, is directly related to the

[1]The first report entitled "World Shale Gas and Shale Oil Resource Assessment" was prepared by the EIA in April 2011. It provided information on world shale reserves expanding on the 69 shale formations within 32 countries. The second report updates a prior assessment of shale gas resources. It assesses 137 shale formations in 41 countries outside the USA.

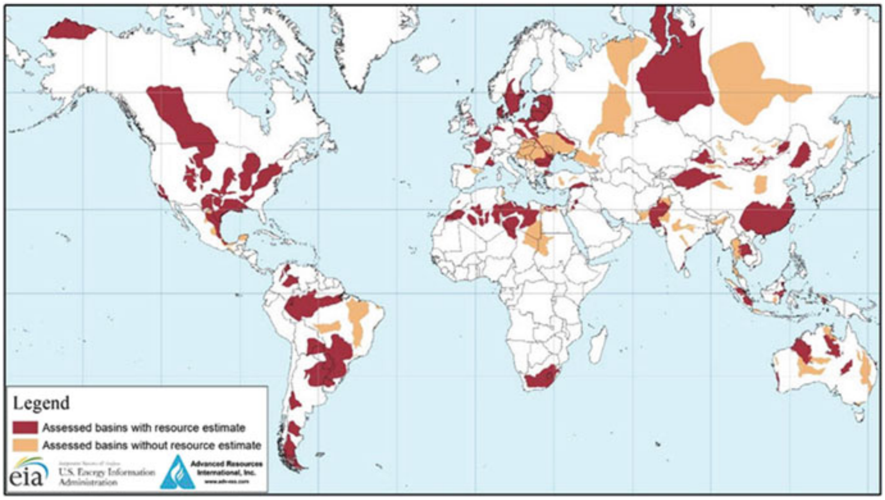

Fig. 1 Map of basins with assessed tight oil and shale gas formations. *Source*: EIA/ARI World Shale Gas and Shale Oil Resource Assessment Report

absence of ongoing projects for the shale gas production, because states of the following region have quit stable income from the operation of conventional oil and gas fields.

However, the sharp decline of world prices for hydrocarbons actualizes the issue of conducting more detailed study of the areas rich in natural resources in order to search for potential shale formations, which in the future could become a kind of "insurance" for the energy industries of the following states. Such approach does not require large-scale production of the potential shale gas in either short or medium term, so it is reflected on both the process of preparation for the geological exploration works and the level of funding approved by the state for such kind of energy industry development.

This statement correlates well with the national priorities of the Republic of Kazakhstan in terms of the national energy sector development.

2 National Strategy for Shale Gas Application

It should be noted that at the legislative level, the Government of Kazakhstan does not have a clear position on the prospects for large-scale production of the shale gas and tight oil, in general, and the introduction of fracking technologies, in particular. Within the framework of national laws approved by the Government, the shale gas and tight oil are mentioned only in the context of the proposed expansion of the use of the alternative energy sources (AESs), although more appropriate to use the term alternative sources of hydrocarbon materials (HM).

For example, JSC Sovereign Wealth Fund “Samruk-Kazyna”[2] has offered for consideration of the governmental agencies a program, entitled “Roadmap (Master Plan) for the Development of Alternative Energy in the Republic Kazakhstan in 2012-2030.” According to this document, the main goals of the announced “Roadmap” are implementation, management, and development of alternative energy and renewable energy in the country. Outlining its strategic vision in this matter, “Samruk-Kazyna” proposes to expand the fuel and energy base of the country by using alternative sources of hydrocarbons, including shale gas, tight gas, methane hydrates, coalbed methane, and bitumen sands.

Although this document is of a recommendatory character and cannot be used as a formal legal act, the mere inclusion of shale gas in the list of AESs shows that Astana could not ignore the recent trends in the global gas market, which are directly related to the so-called shale revolution.

It should also be noted that there is another document on the basis of which the country’s leadership could establish future legal framework for projects for exploration and development of unconventional hydrocarbon resources in the Republic of Kazakhstan – The Scientific and Technical Program (STP) “Development of Technologies for Extraction, Transportation and Processing of High-Viscosity Oil, Natural Bitumen and Oil Shale.” Approved by the Government of the Republic of Kazakhstan, the STP was launched in 2013 in the framework of the JSC National Science and Technology Holding “Parasat”[3] activities.

The desire in the nearest future to conduct geological exploration for the shale gas formations was expressed by the high-level officials. For example, Prime Minister of the Republic of Kazakhstan Massimov K. K. during his presentation at the 25th Meeting of the Energy Charter Conference, which was held in Astana in November 2014, stated that the country was going to develop deposits of shale gas. Therefore, it would allow Kazakhstan to enter the list of Top-10 world energy producers. [4]

Thus, we can conclude that in spite of the increasing rate of unconventional gas production worldwide, Kazakhstan is just at the very beginning of its way of studying the issues related to the prospects of shale fuel production.

[2]Joint-Stock Company Sovereign Wealth Fund “Samruk-Kazyna” was founded in accordance with the Decree of President of the Republic of Kazakhstan dated October 13, 2008 No. 669 “On some measures on competitiveness and sustainability of national economy” Sovereign Wealth Fund “Samruk-Kazyna” is established in order to enhance competitiveness and sustainability of national economy and prevent any potential negative impact of changes in the world markets on economic growth of the country.

[3]The JSC National Scientific and Technological Holding “Parasat” with 100% state participation in the authorized capital established pursuant to the decision of the Republic of Kazakhstan Government dated July 3, 2008. However, on March 11, 2015 due to the order of the Committee of State Property and Privatization of the Ministry of Finance of the Republic of Kazakhstan, JSC “Parasat” was reorganized in the form of division into joint-stock companies National Science and Technology Center “Parasat,” “Science Fund,” and “National Center of Seismology.”

3 Practical Issues

In order to have an opportunity to implement the declared initiatives, Kazakhstan's authorities would have both to decide on the country's strategic plan for the energy sector development and to make some concrete steps in the declared direction. At the initial stage, the primary challenge is to provide accurate data on possible unconventional hydrocarbon reserves located in the territory of the Republic. The systematic study of the traditional oil and gas structures remains the main feature of Kazakhstan's geological exploration sector. Such kind of practice has its roots in the Soviet period and determined sectoral-oriented industry of the country during the indicated historical period.

Considering the need for a comprehensive study on the assessment of the proved reserves of unconventional hydrocarbons on a national scale, including the shale gas resources, there is a need for generating a clear resource ranking system based on the physical parameters of AES, which could help to determine the optimal production technology for each type of raw materials. Due to insufficient knowledge, there is no single terminological base of hydrocarbon materials in Kazakhstan, which would allow clarifying what kind of gas should be called "shale," a "tight," etc.

Some confusion in the classification of particular types of unconventional hydrocarbons can result from the discrepancies in the terminology used in the Western countries and the states of the former Soviet Union. In this respect, it is necessary to create a single list of terms and concepts. In particular, acceptable variant of the unconventional hydrocarbons classification is shown in Table 1.

Based on the following classification, it becomes clear that the Republic of Kazakhstan has some data on stocks of alternative sources of hydrocarbon materials.

For example, there is information about at least 60 high-viscosity oil deposits in the post-salt units of the Caspian Depression, about at least 60 structures and mineral deposits containing natural bitumen, concentrated mainly in the Mangistau oil and gas province. There is also information about more than ten deposits of oil shale, located in the east of the country [5].

However, due to some objective reasons the reliability of the preliminary data on the various sources of hydrocarbons should be called into question:

1. Long standing of conducted research: All publicly available data is dated between 1970s and 1980s of the twentieth century;
2. Research orientation: The geological exploration conducted on the Kazakhstan's territory was mainly focused on searching for the oil and gas fields, so any successful results in exploration of unconventional fuels were not taken into account. Therefore, research groups have not carried out a comprehensive study on discovered deposits because of direct orders of the Soviet authorities;
3. Applied technologies: Due to the lack of necessary equipment, the assessment of the discovered deposits in the most cases was made in the framework of sample calculation.

Table 1 Unconventional hydrocarbons classification

NN	Terms	Description
1.	Heavy crude oil	Natural hydrocarbon fluid with density over 920–1,000 kg/m^3
2.	Natural bitumen	Semisolid mixture composed predominantly of hydrocarbons with density greater than 1,000 kg/m^3
3.	Extra-heavy crude oil	Intermediate form between bitumen and heavy crude oil with density greater than 1,000 kg/m^3
4.	Highly viscous oil	Common term, combining heavy and extra-heavy crude oil
5.	Bitumen-bearing carbonate rocks	Sands and siltstone cemented by solid and semisolid bituminous materials
6.	Inaccessible oil	Remaining reserves of the depleted oil fields, excluded from the balance because of unprofitableness
7.	Oil shale	Minerals from the solid caustobiolites group giving a significant amount of resin, which is close in composition to the shale oil, after the process of dry distillation
8.	Shale oil	Unconventional oil produced from oil shale rock fragments by thermal dissolution
9.	Tight oil	Petroleum that consists of light crude oil contained in petroleum-bearing formations of low permeability
10.	Shale gas	Natural gas that is found trapped within shale formations
11.	Low-grade coal	Ordinary brown coal
12.	Gas hydrates	Crystalline water-based solids physically resembling ice

Source: Nadirov NK (2013) Unconventional hydrocarbon resources of the Republic of Kazakhstan: problems and some possible solutions. Oil Gas 4(76):55–56

It is obvious that a contemporary list of unconventional hydrocarbons deposits should be substantially modified. After a careful investigation, some of the deposits would be excluded due to results of the economic feasibility study [6]. At the same time, the designated list should also be updated with new deposits that were discovered in the oil and gas provinces of the country since Kazakhstan gained its independence.

Due to the fact that the information on current unconventional hydrocarbon resources in Kazakhstan is nonpublic one, it would be very difficult to summarize the following statistical data. By coincidence, the foreign multinational companies, which have the exploration rights to develop oil and gas blocks in Kazakhstan, are trying to prevent disclosing confidential information on both the volume of the raw materials production as well as on the results of geological exploration. In such circumstances, it would be problematic even to make a rough estimation of the unconventional hydrocarbons reserves.

4 Shale Gas Prospective Areas

Despite the lack of primary data on the shale gas deposits in Kazakhstan, experts believe that the country's shale gas potential is significant. At the same time, different experts point out different regions of the country, promising in terms of unconventional gas production.

Since Kazakhstan has a large number of the coalfields, some experts insist that these coal structures should be the start point of the geological exploration of the shale gas. On this basis, the prospective shale gas formations could be found in the southern and central parts of the country. For example, perspective shale gas areas could be Almaty region, namely Kenego-Tekesky and Zharkent blocks, and Karaganda region, where the most promising territories are located near to Zhezkazgan.

Comparing the potentials of the defined regions, preference should be given to the Zhezkazgan block for geological reasons, namely the region is situated at the tectonic crossroad of two major plates: Chu and Sarysu. It also should be taken into account that there are large groups of minerals formations, such as Kumkol, Amangeldy, and Pridorozhnoe gas and oil fields. Finally, according to the data from the exploration wells, which have been drilled in the Talapskaya and Sarysu blocks in 1997, there is an evidence of the unconventional gas formations in the region. This news is encouraging for Kazakhstani researchers despite the fact that the discovered formations have been classified as stranded gas [7].

Alongside with the opinion on prospects for shale gas production in the central parts of the country, there is another opinion, which stated that priority should be given to the geological structures in the western part of Kazakhstan. For example, deposits of tight oil and shale gas could be found in the Caspian Depression, which is partly supported by the results of exploration on the Eastern Akzhar structure, which is located in the eastern zone of the margin of the Caspian Depression [8].

The shale gas exploration could be conducted within the framework of the international oil project "Eurasia," which would be implemented jointly by Kazakhstan and Russia in the Caspian basin during the 5-year period. Although this project is focused on the deep oil and gas deposits exploration,[4] experts would have to proceed geophysical data over the past four decades using the high-technology equipment. Therefore, it would be possible to build a clearer picture of possible structures for further unconventional hydrocarbons production.

As can be seen from Fig. 2, the potential shale gas resources are scattered throughout the country, which means that other gas-bearing shale plays could be discovered. However, it should be recognized that without any results of direct exploration, it is hard to provide even rough estimation of the possible shale fuel production in Kazakhstan.

[4] According to the current research conducted on the 15 sedimentary basins of Kazakhstan, deep oil and gas deposits of the Caspian Depression are estimated at 67 billion tons of oil equivalent and 27 billion tons of oil equivalent are recoverable.

Fig. 2 Shale gas prospective areas. *Source*: Based on Kazakhstani researchers materials

5 Potential Markets for Shale Gas from Kazakhstan

Although currently in Kazakhstan there is no unconventional shale and methane-coal gas production, the governmental officials still have the opportunity to discuss what options would be better for the country. Currently, both high-ranked officials and experts agreed that the price issue would determine which direction of the shale gas distribution would be at the top of the list – external or internal.

If the shale gas price will be able to compete with the natural gas prices, there is a high probability of choosing the domestic market for shale gas distribution. Such an option will solve the gasification problem of Kazakhstan (currently the state could supply gas only to 8 of 14 regions). The shale gas reserves, which could be discovered, may provide the gas supply for the southern regions uncovered by the main gas pipelines, especially if gas stocks would be found in close proximity to these areas.

For example, there is a possibility to gasify Zhezkazgan and its satellite town Satpayev if the large shale deposits or other unconventional gas plays would be discovered at the block Talapskaya. In the middle-term perspective, Karaganda and Astana could also cover their demand in the energy sources after commencement of commercial production of the shale or coal-methane gas field located 20 km away.

However, if the cost of unconventional gas would be too high, all produced volumes should be distributed in the foreign markets. According to the First Vice-Minister of the Ministry of Energy of the Republic of Kazakhstan Urazbai Karabalin, in 2014 the total production of natural gas in Kazakhstan amounted to over 43.2 billion cubic meters. Therefore, Kazakhstan exported only 11 billion cubic meters of natural gas and 12.5 billion cubic meters of natural gas were provided for domestic needs. Remaining volumes of produced gas were used for reinjection into the reservoir to increase oil production by increasing the pressure in the reservoir [9].

6 Potential Risks and Threats

Production and use of unconvertible energy resources always increases the risks for the environment, human health, and safety. In the case of shale gas production, the likely enormous negative impact on the environment could even prevent the full-scale exploration works of the shale deposits in the countries around the world.

Production of gas from shale deposits has specific features. Due to the high density and strength of the gas-bearing shales, the only technology, which allows to liberate the gas from the reservoir, is the hydraulic fracturing (fracking). Since shale has relatively low permeability, the well has to be fracked repeatedly [10, p. 7]. Thus, the extraction of shale gas seriously affects the subsoil and the surrounding ecosystem.

As the environmental issues are critical for the regions of Kazakhstan, the possible decisions on implementing the strategy for the commercial production of the unconventional hydrocarbons of any kind should be extremely prudent.

Nowadays, the most serious environmental problems for Kazakhstan are the following:

– *Land degradation and impoverishment of landscape* – At present, over 76% of the territory of Kazakhstan is affected by desertification.[5] The most heavy desertification is observed in the areas of active development of mineral resources (oil and gas production in the Caspian Sea region, coal production in the Karaganda region, etc.). Significant anthropogenic disturbance is also noted in the south regions of the country, especially, in the areas of irrigated agriculture, oil and gas production, industrial/urban agglomerations – the zonal types of landscapes of the mentioned territories have already been changed by more than 80%. There are also complex processes of impoverishment of biodiversity, and degradation of ecosystems and agricultural land in many regions of the country. At the same time, the world practice shows that the shale gas drilling and production requires great amount of specific equipment and necessary infrastructure – vehicles, frac tanks (water storages), chemicals, proppant, and others. The use of such facilities affects the environment because of the leakage of chemicals, corrosive compounds, fracturing liquid flowback.[6] Therefore, the inevitable pollution occurring during the fracking causes the increasing scale of marginalized areas, which are not suitable for agriculture;

[5]Evaluation was made by the Institute of Geography of the MES.

[6]The part of the solution (from 10 to 90%), which returns to the earth's surface after fracturing and requires costly disposal. At the same time, the other part of the solution, which was injected into the bowels, actually is forming a polygon of underground burial of liquid toxic industrial waste.

- *Water scarcity* – In terms of water availability,[7] Kazakhstan is one of the most water-scarce countries of the Eurasian continent and ranks last among the CIS countries. There is an acute shortage of water resources for the needs of both industry and agriculture, so as for domestic water supply. At the same time, the shale gas production technology supposes free access to virtually unlimited volumes of water. On the average, it can take up to 15 million liters of water to frack a single well [10, p. 32]. The shale gas production affects the water resources in two ways. On the one hand, there are fencing ponds or other sources with the huge volumes of water; on the other hand, there is the contamination of surface and groundwater with toxic gases (methane, ethane, propane, etc.)[8] and chemicals contained in the fluid flowbacks, even if these liquid flowbacks were pretreated;
- *Destruction of ecosystems* – Ecologists express concern over the large number of unique environmental systems in Kazakhstan, namely the Caspian Sea region, the Aral Sea region, Baikonur Cosmodrome, and Semipalatinsk Test Site areas. Experts state that the self-purifying capacity of natural ecosystems in the Republic of Kazakhstan has been already exceeded. Therefore, the new stage of full-scale production of fossil raw materials will only make things much worse;
- *Unfavorable radiation situation* – Due to the vigorous activity of the aerospace industry (Baikonur Cosmodrome), more than 400 surface and underground nuclear/thermonuclear explosions that were carried out at the Semipalatinsk Test Site, so as intensive mining of uranium (1st place in the world), the general situation with radiation and radioecological safety in Kazakhstan reached the critical point. Energy resources production, especially, the shale gas production, is always accompanied by removing of the natural radioactive radionuclides and their cleavage products during well drilling. For instance, radon gas may migrate completely to surface and can penetrate into the houses and office buildings becoming a source of radiation for employees and population;
- *High degree of air, soil, and water pollution* – Kazakhstan occupied the 23rd place in the world according to the list of the countries with the highest amount of the greenhouse gas emissions, also the Republic takes the 3rd place among the CIS countries (after Russia and Ukraine) and the 1st place among the countries of Central Asia on the same indicator. Considering that the shale gas extraction leads to emissions of methane and other gases, which together cause the global warming, and also that the concentration of the mentioned gases is much higher during the fracturing comparing with the conventional gas production, it becomes clear that if Kazakhstan launches the large-scale production of the

[7]Specific water supply per unit area and per capita.

[8]The methane concentration can greatly exceed the safe level. It can cause explosions, because methane is not explosive unless it is mixed with oxygen. For instance, there was Pennsylvania case when the water taken from local wells was on fire.

shale gas, it will affect negatively the situation with greenhouse gas emissions over the country.

Therefore, international experience shows that traditional and nontraditional gas production (gas-bearing shales and coal seams) affects significantly the environment, namely the geological structures, underground and surface water, air, soil, and land.

It should be noted that the environmental risks associated with the development of shale gas plays cause both pollution and degradation of the natural environment, and consumption of great volumes of water being the most precious natural resource.

In addition to the direct threats for environment and human health, there are also indirect risks related to the fact that the redistribution of financial supports and effort for the shale gas production industry would decelerate development of the renewable energy sector. Such processes can be easily observed in many countries worldwide.

The ill-considered attempts to develop any unconventional energy source, especially, the shale gas, which has bad environmental reputation, can greatly aggravate the environmental problems in the Republic of Kazakhstan and cause the negative effect on the economy of the country and social well-being of its citizens. After using of the fracturing technologies, there would be the need for great investments into damaged ecosystems restoration, providing medical assistance to the population and possible resettlement of the people from the areas of environmental degradation.

On the other hand, the technology is not standing still. In this regard, the further development of shale gas extraction industry on a global scale will depend on the successful addressing of the environmental and social risks associated with the shale hydrocarbons production.

7 Conclusion

Due to the lack of geological data on potential gas plays, the absence of clear legislative acts on the shale gas production issues, and the high level of environmental threats and investment risks during the shale gas technologies development, it would be rather problematic to start implementation of the state strategy that is focused on the shale gas production in Kazakhstan.

However, it does not mean that the authorities of the country will not attempt to establish production of other types of unconventional hydrocarbons. For instance, Kazakhstan's Gas Production and Transportation Company "KazTransGas" and Saryarka social-entrepreneurial corporation signed the agreement on exploration of the coalbed methane at the Karaganda coalfield.[9]

[9]The cooperation agreement was signed on April 3, 2015. The two companies will conduct joint exploration and research works to develop the most optimal coalbed methane production technology. Earlier this year, KazTransGas signed a memorandum of cooperation in exploration and production of coalbed methane with Gazprom Dobycha Kuznetsk, a subsidiary of Russian gas giant Gazprom.

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China Stakes on Shale Gas

Igor S. Zonn and Sergey S. Zhiltsov

Abstract The shale gas production in the USA was not missed in China for which the issues of hydrocarbon export and development of own resources are always in the focus of attention of its leadership. Preliminary investigations conducted in China have revealed considerable reserves of shale gas. The great attention to this hydrocarbon resource was supported by the special decision of the Chinese authorities that in 2011 officially referred the shale gas to individual mineral resources. In 2011–2015, energetic efforts were made in China to organize the shale gas production in commercial scales, thus, to reduce its dependence on gas import from Central Asia and other world regions.

Keywords China, Ecology, Production, Reserves, Shale gas

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Contents

1 Introduction

China takes a special place in discussions of shale gas. China is interested in extension of the shale gas production due to likely reduction of its dependence on hydrocarbon import and in the face of soaring demand for gas in the recent years. In 2009, this demand showed the 20% growth and in the next years it maintained quite sustainable growth rates.

China is seeking to offset the reduced share of coal in its energy balance with gas. For this purpose, Beijing has concluded contracts for delivery of liquefied gas from Australia, and cooperates actively with Turkmenistan in the implementation of gas pipeline projects that will bring Turkmen gas to China [1]. However, these efforts are not sufficient to cover the requirements of China in hydrocarbons. Consequently, China is still interested in development of its own shale gas plays. According to experts from the China National Petroleum Corporation (CNPC), by 2020 the demand in natural gas in China will be as high as 270 bcm.

The intention of China to develop its shale gas plays stirs great interest in the USA. The US companies were seeking to circulate and resale the shale gas production technologies as wide as possible. The technologies of the shale gas production were discussed during the visit of the US President B. Obama to Beijing in November 2009. As a result, the USA and China concluded the framework agreement, the key point of which was the technological support for China by the USA in development of the shale gas plays [1]. This political marketing of the US technologies was accompanied by the really global PR campaign involving the leading consulting companies, the major oil and gas corporations, and governmental agencies, both the US and international [2].

China as well as other world regions possessing considerable shale gas resources has no accurate data of their hydrocarbon reserves. Wide scattering of reserve assessments published in scientific researches and mass media may be connected with the too short period of geological surveys. Thus, the Chinese data and the assessments of international research centers and foreign oil and gas companies differ greatly. Nevertheless, all researchers agree that China possesses considerable shale gas reserves, but their development involves many difficulties.

Fig. 1 Major shale gas basins in China (http://www.cnpc.com.cn/en/UnlockingTightGasandShaleGasPotentia/UnlockingTightGasandShaleGasPotentia.shtml)

2 Shale Gas Reserves

The progress in the shale gas production attained in the USA enhanced the interest to this problem in China for which the energy security has become the key issue in the recent decade. In 2010, the State Research Center for Shale Gas [3] was established in China, which emphasized how important for China were the issues related to investigation of shale gas plays, development of new technologies, and studies of environmental consequences.

Significant shale gas reserves in China are found in two basins – Sichuan in the south of the country and in Tarim in the west (Fig. 1). These two basins have thick series of shales rich in organic substances spreading extensively and possessing good collecting properties for their development [4]. The data on the shale gas resources trapped in them are illustrated in Table 1 [5].

The Sichuan basin located near the water sources is surveyed most actively. China suffers from water shortage and the factor of water availability becomes the key one.

Rough data of the shale gas resources in China have shown that this country possesses considerable reserves of this hydrocarbon. By late 2011, some wells were drilled in the shale rocks in China, while in 2011–2013 several dozens of them were

Table 1 The shale gas resources in the Sichuan basin and Tarim basin

	Sichuan basin	Tarim basin	Total
Risky geological resources (tcm)	78.3	66	144.3
Risky recoverable resources (tcm)	19.6	16.5	36.1

drilled. For this reason, the assessments of the shale gas reserves cannot be considered proven. According to experts of the Chinese Ministry of Land and Resources, only dozens of wells were drilled in different regions of the country for assessment of the resource base. This is, obviously, quite insufficient to present the full picture of the available shale gas resources.

Regardless of the limited scale surveys that confirmed only the probable shale gas reserves, China still asserted that it had the largest shale gas reserves. Publication of such figures was taken into account in decisions of state authorities. In March 2012, China presented the Plan of the Shale Gas Development for 2011–2015 that envisaged extensive surveys of shale rocks and it was expected that around 200 bcm of technically recoverable shale gas resources would be investigated.

In 2012, China continued drilling of wells applying fracking technologies in each. The drilling was conducted by China Petroleum and Chemical Corporation (Sinopec), Yanchang Petroleum, PetroChina, and CNPC. And only 25% of the drilled wells provided good shale gas flow. The first success urged China to announce about availability of new, verified data obtained as a result of drilling in main shale plays. Accordingly, it became widespread that the shale gas reserves in this country reached 134.42 tcm, which moved Beijing to the circle of countries possessing the world's largest shale gas reserves [6].

In the same year, the Chinese Ministry of Land and Resources published the Report on the Oil Resources Development Abroad saying that the technically recoverable shale gas reserves in the world reached 187 tcm, out of which 36 tcm were found in China. Based on these data, China takes the first place by the shale gas reserves outrunning such countries as the USA, Argentine, Mexico, and SAR [7]. According to this document, by 2020 the shale gas production entered the period of quick development and the annual output should exceed 100 bcm.

The USA also published its data about the shale gas reserves in China. According to rough estimates of the US Department of Energy, the shale plays in China may trap 12 times more gas than traditional gas basins and their reserves are assessed at 26 tcm. The data of the US experts practically coincided with the data of Chinese researchers. Thus, the National Development and Reform Commission of China assessed the shale gas potential at 28 tcm.

In 2014, the verified data on the shale gas reserves in China were made public. According to the US DoE experts, China possesses the world's largest resources of shale gas – 31 tcm, or 15.3% of the total shale gas reserves [8].

In 2015, the reserves of 26 shale plays discovered in China were evaluated at 25.08 tcm. In November 2015, the new data about the proved geological resources of shale gas in China were published. According to the most recent data published in China [9], they made already 106.8 tcm. And although the country has not yet triggered the “conveyor” of shale gas production and still faces many difficulties in the development of this business, it is believed that by 2030 the country will be one of the largest shale gas producers in the world [10]. China assumes that the efforts made in this area will permit to increase the shale gas production to 60–100 bcm.

3 Shale Gas Production

The shale gas production business in China is controlled by the state. The China’s policy in this area is developed based on the data of experts asserting the availability of considerable shale gas reserves in the country.

The shale gas production in China was started in 2010 in the Sichuan basin. The China Petroleum and Chemical Corporation (Sinopec) got the commercial scale flow of shale gas in two parts of the Sichuan basin – in the northeast near Yuanba and in the southeast near Fulin.

The survey and prospecting works are underway in the Tarim basin located in the west of China possessing the largest shale gas reserves. The main obstacle here is the arid climate which is a serious constraint as the fracking technology requires much water.

In mid-2011, China conducted shale gas exploration competitive bidding and invited four state-owned major oil and gas companies to participate in bidding. As it was already mentioned, in the early 2012 China started drilling in shale plays. Half of the wells produced gas. However, the volumes of extracted gas were not large (Fig. 2).

China started inviting the world oil and gas giants having the required technologies to prospecting and development of shale plays, such as Chevron (USA), BP (Britain), Royal Dutch Shell (Britain–Netherlands), Total (France), and Statoil (Norway). The largest Chinese corporations such as CNPC, China Petroleum & Chemical Corporation (PCC), and China National Offshore Oil Corporation (CNOOC) actively cooperate with the Western companies. The trial drilling is conducted in the Sichuan province. In addition, China organized the tender for shale gas prospecting rights in the territory of 11,000 km^2 in the Guangzhou province and Chongqing municipality in the southwest of China.

In September 2012, China announced about the second public tender for the sale of shale gas prospecting rights. This time, state companies and private Chinese companies as well as joint ventures with foreign companies with the Chinese controlling share were admitted to participate in this tender. It is quite obvious that China will do everything possible to increase the production of unconventional gas disregarding the environmental detrimental consequences. The seriousness of the China’s intentions was confirmed by setting up of the Chinese National Energy Administration (CNEA) for research of shale gas in Langfang, near Beijing, to be sponsored mostly by PetroChina Ltd., the subsidiary of CNPC. The studies of shale

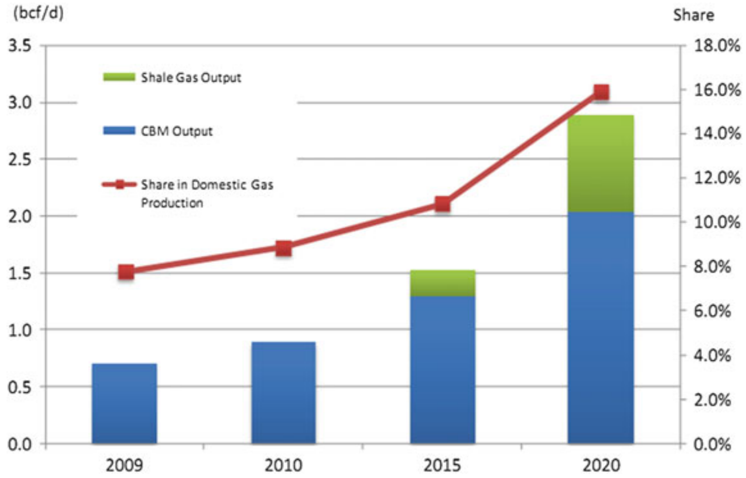

Fig. 2 Unconventional gas production in China (http://www.endofcrudeoil.com/2013/03/chinas-shale-gas-dream.html)

technologies are conducted by various institutions headed by the Guangzhou Institute of Geochemistry of the Chinese Academy of Sciences.

In the early 2013, China conducted the next auction for the right to develop 20 shale areas in which the successful bidders were 16 national companies that have never drilled wells. They intended to conduct drilling in cooperation with such foreign partners as Schlumberger and Halliburton. The Chinese government plans to promote this sector of the economy and by 2020 to increase by 10% the total shale gas production due to the development of shale areas. In the 2009–2014 timeframe, China had invested US$3.7 billion into shale gas prospecting and development.

4 Production Forecasts

Still prior to commercial extraction of shale gas, a great number of forecasts started appearing in China. As in many world countries, the projections of shale gas production in China differed greatly, too. Thus, first it was published that by 2015 China was going to increase production by 30–50 bcm, largely, due to shale gas extraction. In April 2011, the Chinese officials asserted that the first shale gas would be produced by 2015. Deputy Senior Economist of SNPC Planning Department Sun Syaodan detailed on the vision of the Chinese leadership having said that the plan of shale gas production till 2015 was approved. This plan envisages extraction of 6.5 bcm of shale gas and by 2020 it should reach 80–100 bcm [11]. By 2015, CNPC proper should produce 1.5 bcm of shale gas.

Based on such projections, the Chinese officials developed the policy on shale gas play development. In 2011–2015, the Chinese government set the goal to create the basis for large-scale development of this business in the next 5 years. In 2014, the special program of subsidizing the companies engaged in shale gas production was suggested. A producer should get 6 cents per each extracted cubic meter of shale gas which after recalculation per thousand cubic meters gives additional payment of 64 USD.

The assessments of the leading energy institutions and consulting agencies of the prospects of the shale gas production in China till 2030 differ even greater – the extraction of unconventional gas is expected to vary from 57 to 114 bcm. In 2020, the share of this hydrocarbon in the total gas production will reach 17% and by 2030 – 44%. In absolute figures, this makes 14 bcm and 57 bcm of gas, respectively [12].

China has no extensive pipeline network that could supply the extracted gas directly to users. In the early 2012, CNPC arranged with the Shell Concern about setting of a joint venture that would extract gas in the Sichuan province on the production sharing basis. The companies had equal shares in this venture and Shell should bring technologies of shale gas production tested in North America, in particular, of automatic directional drilling. As a result, this joint venture should have become a part of the world alliance of the major oil and gas companies of Europe and Asia. It was announced that time about construction in China of the first pipeline for shale gas transit with a capacity of 36 mcm per year.

So far, the leading company producing shale gas in China is Sinopec. It extracts small quantities of shale gas in the Fulin play in the Sichuan province in the southwest of China. In 2015, the company plans to complete the preparatory works and to start the production, increasing the output to 5 bcm.

5 Problems of the Shale Gas Production

The development of the shale gas production in China is held back by various problems. China faces serious difficulties in shale gas production connected with complicated geological conditions. The Chinese companies have to drill to a depth of 4–6 km (compare in the USA to 3 km). Due to specific geological conditions of shale plays, the fracking technology requires 30% more water than in the USA and here it should be remembered that many regions of China suffer from water shortage. In general, the problem of availability of water resources required for development of the shale gas plays is more acute in China, than in the USA. And water deficit is growing especially in the regions where the shale gas reserves are most abundant [13].

Unlike the USA where shale gas occurs not deep which makes it more accessible, in China the main shale gas reserves are found in the far away Sichuan province at great depths. Accordingly, the shale gas production in China is technologically more complex and requires great investments. As a result, this sector develops at a slower pace than it was expected earlier due to a number of factors beginning from more complex geological structure of local shale plays to the shortage of water and energy required for their development [14], which increased sizably the cost of drilling of one well – in China it ranges from 5 to 12 million USD, while in the USA it is around 2.7–3.7 million USD. One more problem is the lack of experience. As a result, the forecasted volume of shale gas output (80 bcm) by 2020 is quite doubtful. China may achieve such production level only by investing heavily into this sector with simultaneously abolishing the state control of hydrocarbon prices.

6 Shale Expansion in China

Apart from developing its own shale plays, Beijing shows great interest to the shale gas extracted in other countries. The Chinese companies purchased the shares in the North American shale projects. China is trying to adopt their experience and technologies. In 2009, Chinese PetroChina invested US$1.8 billion into joint development of two shale plays in Canada with Canadian Athabasca Oil Sands.

In the early 2010, the Chinese companies spent around US$46 billion on the purchase of such assets. China actively purchased the shares in development of technologically complex oil and gas plays in North America not only for getting access to technologies. So, Chinese company China National Offshore Oil Corporation (CNOOC) extended its cooperation with the US Chesapeake Energy having purchased one-third of the Eagle Ford play for US$1.1 billion [15]. In this way, Beijing intended to ensure its future energy security.

In February 2011, the Chinese companies signed some more agreements on purchase of the shale gas production assets and among them is the agreement with the Canadian Encana, the largest shale gas producer in North America, on joint development of the shale gas play in Canada. Under this agreement, PetroChina and Encana would jointly develop the Cutbank Ridge play. The proven resources of this play make 28 bcm, and the output will be around 7 mcm per day. The project also includes 3,400 km of gas pipelines and the underground gas storage. The play covers a territory of 5,260 km^2 in the British Columbia and Alberta states. Moreover, CNOOC purchased one-third of the Niobrara play in the Colorado state for US$1.3 billion. Other Chinese company Sinopec purchased from Devon Energy the shares in the plays located in the Ohio, Louisiana, Oklahoma, and Michigan states.

Investing into the purchase of companies and some plays was considered in Beijing as its strategic goal. This was made with a view to get access to the shale gas extraction technologies lacked in China. In fact, the transnational companies engaged in the shale gas production act as technological donors [16].

The enhanced attention to wider cooperation with foreign countries and purchase of assets in other countries were connected with the difficulties faced in developing Chinese shale plays. Poor geological study of plays, environmental constraints, water shortage, and lack of own extraction technologies [2] are the factors that pushed Beijing to cooperate with foreign companies in shale play development and purchase of foreign assets. In March 2015, the Chinese CNPC announced about its plans to join the US shale projects. Earlier China Petrochemical Corporation (CPC) invested over US$1 billion into oil fields in Oklahoma (USA). Besides, CNOOC made a major purchase – the Canadian Nexen Corporation for US$15.1 billion. In the second half of 2015, China pursued further its policy on acquisition of foreign assets connected with the shale gas production. The Chinese state-owned companies invested more than US$6 billion into purchase of shale gas assets in North America.

7 Conclusions

Regardless of the difficulties with exploitation of shale plays, China continues to keeping their development in the focus of attention. So far, the efforts in this direction go on at a slow pace as Beijing receives liquefied gas and pipeline gas. However, in the future the situation may change due to the appearance of new technologies of shale gas production and price factors [8].

Still prior to careful researches to verify the shale gas reserves in the Chinese territory and producing the first flow of this hydrocarbon, the long-term projections were formulated that predicted quick rise of the shale gas production. One of such projections said that by 2020 China would produce up to 100 bcm of shale gas. This permitted Chzhan Davey, Deputy Head of the Center for Strategic Research of Oil and Gas Resources of the Ministry of Land and Resources, to announce that this would help to change completely the energy structure in China [17]. The implementation of this objective determines the policy of the Chinese leadership. In the late 2015, the Chinese government planned to expand the shale gas production by establishing the wider cooperation with the British-Dutch Royal Dutch Shell and American Chevron.

In the next 1–2 decades, the role of unconventional gas in China may grow significantly and become one of the key factors for promotion of gas production. It was noted that by 2030 China could become one of the leaders in the production of not easily recoverable gas [18].

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The Role of Shale Gas in the Global Energy

Sergey S. Zhiltsov and Aleksander V. Semenov

Abstract The rapid increase of the shale gas production in the USA has influenced significantly the global energy market. Primarily, this is connected with a sharp decrease of natural gas import by the USA. Moreover, the scenarios of the US shale gas supply to the European market that turned out to be under strong impact of the "shale revolution" have been discussed actively. Other world countries possessing shale gas reserves are also planning to increase its production. Although the first results of export of the "shale revolution" have shown that quite unlikely the US experience of this area will be repeated in the next decade, but, still, with regard to the volumes of the shale gas production the global energy market is already altering notably.

Keywords Energy, Shale gas, World politics

Contents

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1 Introduction

The rapid growth of the shale gas production in the USA has brought this hydrocarbon into the focus of attention practically in all world countries. The publication of data on availability of some fantastic reserves led to appearance of a wealth of projections about future scenarios of development of the global energy market as well as particular regional markets. Moreover, the first results of the “shale revolution” provoked a new round of geopolitical rivalry for the European gas market.

With good reason, the US efforts to move the “shale revolution” to Europe may be considered as a geopolitical project targeted to attain the long-time objectives. In July 2011, the James A. Baker III Institute for Public Policy at the Rice University published the report entitled “Shale Gas and U.S. National Security” where the shale gas was considered as an important instrument for extending the US geopolitical influence. The authors of this report marked that the growing supply of shale gas had already involved its geopolitical consequences being the key factor in weakening the possibilities of Russia to use its “energy weapon” against its European users by increasing the alternative deliveries to Europe of liquefied gas ousted from the US market [1].

In different world regions, the development of shale gas plays causes rivalry among countries. This factor affects the promotion of some pipeline projects that turn into the instrument in the struggle for gas markets.

2 The European Policy Got into the Shale Flow

The plans to develop shale gas plays in Europe stirred new discussions about the fate of future pipeline projects. In particular, the European countries stressed high dependence on the Russian pipeline gas imports. This factor influences the development of foreign policy by some European countries. It is also used in negotiations with Russia on supplied gas price. However, different approaches of the EU countries to reduction of dependence on the Russian gas mostly suppose cutting of the volumes of the Russian gas imports. Such stand of European countries is formed, to a great extent, under the USA influence.

The USA persist in promoting the idea of diversification of the Europe energy sources by extending the shale gas supply to the European market. In this, the USA is facilitated by considerable dependence of some European countries in their foreign policy. It is not accidental that in the recent decade the EU has been discussing whether it is feasible to implement the costly projects on construction of pipelines from the Caspian region and Central Asia or may it's better to wait some time for implementation of the shale gas projects [2].

Receiving news from the USA about increase of the shale gas production, the EU becomes more doubtful whether the pipeline projects are needed. The most well-known project that the EU has tried to accomplish since 2002 is the gas line Nabucco. This project has been discussed for about 10 years; it should be an additional solution for diversification of the EU gas supply, in particular, from Central Asia and Iraq. In July 2009, the intergovernmental agreement for this project was signed by Turkey, Romania, Bulgaria, Hungary, and Austria. It was aimed both to reduce dependence of Europe on the Russian gas and to creation of new transit routes for the Caspian resources, thus, consolidating the political ties of the Caspian countries with the EU. According to the official statements, this project was not accomplished due to its high cost and lack of free gas resources. At the same time, the "shale factor" also affected the promotion of this EU project [3]. Moreover, with the extension of the shale gas production the likely scenarios of its alternative supply to Europe were developed; consequently, it became more unclear whether the Nabucco project would take geopolitical or commercial dimensions in the future [4].

3 Potential Participants of the "Shale Revolution"

In the recent decade, the main attention was focused on the USA that increased the shale gas production and had already influenced the global gas market. The EU is in the focus of the US policy as it is considered one of the potential regions for export of shale gas from the USA.

Apart from the European countries possessing considerable shale gas reserves, the USA pays much attention to other regions and countries (Fig. 1). Thus, significant shale gas plays were found in such Canadian provinces as British Columbia, Alberta, and Quebec and the largest of them are Horn River and Monti [5]. In general, the proved shale gas reserves in Canada are assessed at 11 tcm. The most perspective of them is the Utica Shale play (Quebec) containing 113 bcm of shale gas [6].

In Australia, the shale plays are found in the Cooper, Canning, Maryborough, and Perth basins. The total shale gas reserves are estimated at 11.2 tcm. In 2011, the first shale gas was extracted in the Cooper play. However, the main constraints for the growth of shale gas production are transportation problems and high labor cost.

Certain shale gas reserves are found in Britain. In June 2013, the governmental report was published where it was asserted that around 3.7 bcm of shale gas was found in the north of the country.

The Mexican government develops plans on the shale gas production. By developing the Eagle Ford shales, Mexico is expecting to extract up to 14 bcm of

Fig. 1 Potential shale gas reserves in the world (http://cdn.energytribune.com/wp-content/uploads/MAP2.jpg)

shale gas by 2026. If the La Casita shale play will be also developed, then the projections should rise to 34 bcm of shale gas [7]. According to unconfirmed data, considerable shale gas reserves may be found in India.

Substantial shale gas reserves are contained in Ukraine, although there are no accurate assessments. The shale formations found in Ukraine take their origin in Poland, pass across four western regions of Ukraine – Lvovsky, Ivanovo-Frankovsky, Zakarpatsky, and Chernovitsky – and reach its central part in the Donetsk – Pre-Dnieper Depression. Ukraine focuses its attention on the shale gas plays Yuzovsky (Donetsk and Kharkov regions) with the reserves of 4 tcm and Odessky (Lvov and Ivanovo-Frankovsky regions) with the reserves estimated at 2.98 tcm.

Therefore, many countries possessing potentially significant shale gas reserves make attempts to develop them. In all likelihood, this will require some decades when the forecasts of reserves are verified, less hazardous production technologies are developed, and the industrial base required for development of shale plays is created. In addition, the countries should make not a simple choice between production of hydrocarbons and water resources whose deficit gives rise to internal and interstate conflicts [8].

The political consequences of the shale boom will not be reduced to the changed alignment of forces in the global gas market. Many countries have to make adjustments in their energy diplomacy in view of the fact that more and more gas will be offered at prices which with time on can compete successfully with traditional natural gas. In the recent decade, such tendency has been gaining strength, but so far it has created potential threat to traditional gas exporting countries, such as Russia, Iran, and Near East countries. At the same time, the importing countries in Europe and Asia are free to choose gas producers.

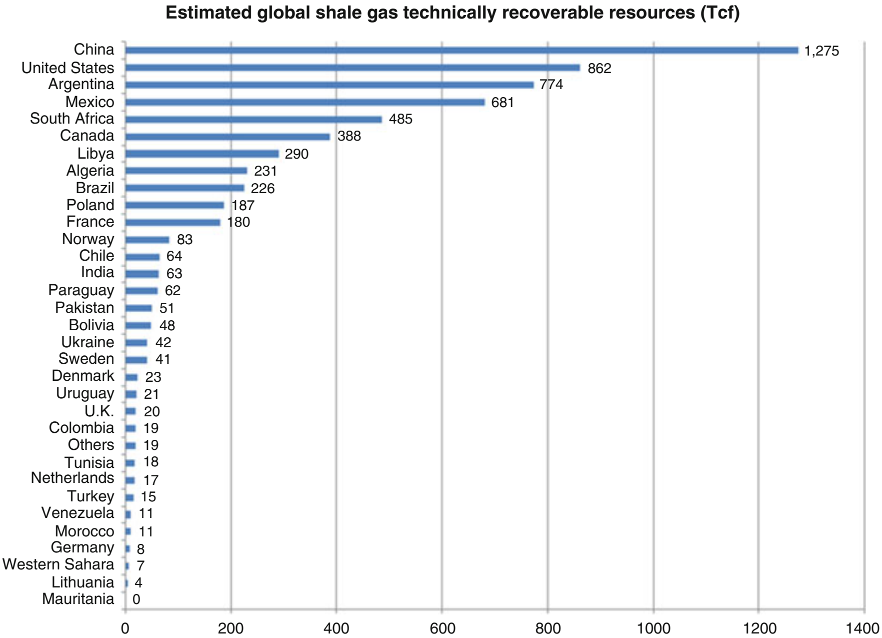

Fig. 2 Shale gas technically recoverable resources by countries (http://3.bp.blogspot.com/-vBaFLDhKINA/TZ0bdlzQZZI/AAAAAAAAHG4/JRTIpiIv5-Y/s1600/worldnatgas.png)

The progress in shale gas production will change the energy policy of China. The need to import oil and gas will force China to extend cooperation with the countries taking special place in the global politics. In particular, availability of enormous gas resources in Iran may push China to widening the political and economic contacts with this country in order to ensure the energy security of China.

At the same time, if China managed to organize its own shale gas production, then it may reduce the gas import. The first results of shale play development have shown that China cannot repeat the US "shale revolution." However, the stage-by-stage development of this hydrocarbon will help China to decrease the gas import (Fig. 2).

4 Russia Under the Shale Gas Pressure

So far, we are witnessing the virtual rivalry between Russian pipeline gas supply to Europe and export of US shale gas progressing in view of depletion of traditional gas sources. Prior to the "shale revolution," it was expected that gas production in the USA, Canada, and in the North Sea would drop significantly which might lead either to the growing share of Russian gas in the European market or gas produced in other regions. In any case, it meant greater dependence of European users on export.

The shale gas has changed the course of events giving rise to rivalry among energy companies engaged in shale gas production and countries exporting pipeline gas. So far, this rivalry concerns largely the technologies as one of the key factors that may make shale gas more attractive is its relative low cost. It is meant here the improved fracking technology using longer than before horizontal wells and injection of the greater volume of water for fracturing. Owing to this already in 2015, the US companies expected to lower the production costs [9]. This fact may also explain the campaign unrolled in 2015 on promotion of shale gas and appearance of new forecasts stating that in one or two decades the shale gas production in the USA should demonstrate the three to fourfold rise. The USA is expecting to attain such goal by improving the shale gas production technologies.

In this context, the growth of the shale gas production in the USA may have certain consequences for the geopolitical and economic interests of Russia. And very important here will be the decision of the USA on development of export of liquefied natural gas (LNG). The growing supply to international gas markets will create additional pressure on Russian gas supply to Europe and Asia. It should be also remembered that in the long-time perspective the cost of Russian gas will grow as Russia will have to develop new fields located in complicated climatic conditions of the North, including in offshore areas [10].

In the USA, the consequences of the shale gas production are already visible – the terminals for LNG import are idling and the likelihood of the USA growing dependence on import becomes less and less. Moreover, the growing production of shale gas in the USA means that LNG from Qatar will be directed to the European market.

The persistent effort of the USA to thrust the "shale revolution" on other countries positioning it as allegedly universal means for attaining energy independence is a poorly disguised endeavor to cut by any means the oil and gas revenues of Russia. This will inhibit the strategic perspective of dynamic development of technological upgrading of economics and military–industrial complex of Russia – the process capable to return Russia its lost status of superpower.

5 US Energy Policy

Promoting the "shale revolution" in Europe, the USA continues to do everything possible and impossible to maintain its influence in the traditional oil and gas regions in Near East, Middle East as well as in Central Asia and in the Caspian region.

This policy got additional impulse after breakdown of the USSR when the new geopolitical processes started gaining strength. The close attention of the USA to Central Asia and Caspian region was dictated by the enormous hydrocarbon potential there. This factor determined the US approaches to pursuance of its multi-aspect and multi-faceted polity in the Caspian region, thus, shaping a new model of international relations after the end of the cold war period [11].

Hydrocarbon resources, pipeline projects, and shale gas production became the important factors of the US energy policy. The energy aspect is the key issue in the system of US foreign policy actions [12].

The fall of the oil prices observed in 2014–2015 can make adjustments in the shale gas production in the USA proper. And the more so as in such situation the shale play development becomes less attractive. Persistence of low oil prices will lead to an abrupt reduction of drilling in the USA and production decrease. The safety margins of US companies engaged in shale play development are rather limited and the considerable debts and profit reduction should be added here.

The USA was always an active player in the world gas trade. The US "shale revolution" permitted the country to change orientation from import of Canadian pipeline gas and LNG from Near East to gas export [13]. However, in North America the "shale revolution" is only unwinding, while in other world countries it has not been commenced as yet. There are different reasons obstructing the shales development: inability to use technologies, technical difficulties, underdeveloped infrastructure, and inadequate legislative base. Accordingly, no one can say when this "shale revolution" will occur in other countries and whether this is possible at all [14].

So far, the USA has not succeeded to export its "shale revolution." Many countries are not ready to spend much money and to face environmental risks [15]. Thus, the "shale revolution" in China, unlike the USA, did not happen owing to more complicated geological structure of local shales, and water and energy shortage required for shales development. The European shale boom was stopped not in the least by ecologists [16]. Consequently, according to forecasts, by 2025 Europe will produce the insignificant volume of shale gas as its reserves and conditions of extraction differ radically from the US plays [5]. In general, according to projections of the International Energy Agency, the shale gas production by 2030 will not exceed 7% of the total world production.

Nevertheless, it should be noted that the shale gas production in the USA influenced perceptibly the US economy. Thus, the shale gas has changed completely the US petrochemical industry. It is widely used not only in production of polymers, but of mineral fertilizers, too [17].

6 Conclusions

Considerable growth in the recent decade of the shale hydrocarbon production (oil and gas) gave a powerful impulse to alterations in the global gas market. Simultaneously, the interest to development of new technologies called to reduce the costs of shale gas and oil production has also increased.

The factor of "shale revolution" influenced greatly the energy policy of many countries exporting and importing oil and gas. Europe, Russia, and China have to respond to the quickly changing situation in the global hydrocarbon market.

The so-called shale revolution dealt a serious blow upon the system of oil and gas supply established in the recent five decades, and enhanced uncertainty in the supplier–consumer relationships. With all diversity of forecasts, it can be said with assurance that the formation of the shale segment continues its pressure on the world gas market that has really acquired the global dimensions.

The shale gas will affect most strongly the regional markets. The main attractiveness of shale gas is its closeness to the final user which cuts significantly the transportation costs.

The effect of shale gas on particular regional markets will differ greatly owing to the unique features of each market. All this may lead to significant geopolitical changes which will affect, in their turn, the world politics. At the same time, it is too early to speak about the decreased role of hydrocarbon supply via pipelines. Availability of considerable oil and gas reserves, developed infrastructure, and availability of efficient technologies remain the important factors that will keep pipeline projects feasible.

Shale hydrocarbon production is closely intertwined with food security and water resources. All three issues are closely interconnected and their solution requires an integrated approach and long-term planning by many world states [18].

Shale gas production alters the foreign policy of many countries provoking the new lines of competition and changing radically the alignment of forces in the world and regional energy markets. The extraction technology of shale gas whose reserves may be found in many world countries, including those that were earlier referred to gas producers, may result in cardinal change of the situation. And the more so as many countries, primarily, the main producers and consumers of hydrocarbons are involved in the shale gas production, directly or indirectly.

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Shale Gas Production and Environmental Concerns

Igor S. Zonn, Sergey S. Zhiltsov, and Aleksander V. Semenov

Abstract The shale gas production in the USA has stirred environmental concerns in the face of the impacts arising in the course of the shale play development. Such enhanced interest of the public to this issue is connected with the opinions voiced by ecologists about the negative impacts of the shale gas production on the natural environment and human health. And the key negative factor is considered to be the hydraulic fracturing (fracking) technologies. It is thought that the hydraulic fracturing affects the geological structures, underground and surface waters, atmospheric air, soil, and land condition. Moreover, the preparatory works for construction of the required infrastructure and also the very process of shale gas production – drilling of horizontal and vertical wells, use of water resources, and

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storage of toxic wastes are also detrimental in this respect. All these factors have led to wider public movement against the shale gas production.

Keywords Climate, Ecology, Environment, Law, Production, Shale gas

Contents

1 Introduction

Many countries have already amassed some experience of shale gas extraction. But the leading positions in shale play development are still with the USA that has demonstrated quick rise of this gas production and is currently preparing plans to export this hydrocarbon resource to other world regions.

Three environmental issues should be addressed in shale development: to find considerable volumes of water, to ensure the acceptable level of technogenic impact on environment during pumping of working solution, and to utilize safely the generated slime [1].

While developing new technologies that permitted to boost quickly the gas extraction, the oil and gas companies also faced negative impacts. They are primarily connected with the specific features of shale gas production, i.e., application of hydraulic fracturing technology (fracking) being the only technique to frac the rocks and to bring the shale gas to the surface. In order to increase gas output, the multiple fracking should be applied which enhances the negative impact on the environment and man.

The growing attention to environmental issues in other countries and, first of all, in Europe may be attributed to tougher requirements of local legislations to comply with the norms contained therein. Moreover, the population protests against the shale gas production due to high population density in these countries. Unlike the USA where the shale gas is extracted in sparsely populated areas, the European countries are densely populated, hence, such great anxiety concerning this hydrocarbon production.

2 Environmental Issues of the Shale Gas Production

Assessing the environmental impacts of shale projects, the following kinds of pollution and disturbances become most important (Fig. 1). First, geomechanical disturbances, i.e., deformation of the rock massif and landscape revealing itself in compaction, loosening, appearance of caves, dumps, and quarries. Second, hydrodynamic disturbances connected with flooding of relief with wastewaters or runoff depletion, groundwater rise, changes of water salinity, turbidity, and temperature. Third, biomorphological disturbances connected with destruction, alteration of the species composition of phyto- and zoocenosis, decreased productivity, and reduced area of flora and fauna distribution. And, finally, lithosphere pollution caused by construction of quarries and wells (Fig. 2), surface and subsurface wastes burial, oil spills, movement of drilling mud into a formation, fluid injection for fracking, and change of the hydrogeological regime in soil [2].

The fracking technology of shale gas extraction is designed to unite small individual gas "pockets" to make a total volume. This process envisages constant horizontal drilling, i.e., the territories and permanent fracking are required and, consequently, great volumes of water. Here water tightness of all formations encountered on the way of well boring acquires special importance. And the more so as a great risk of pollution may appear at breakdown of adjacent

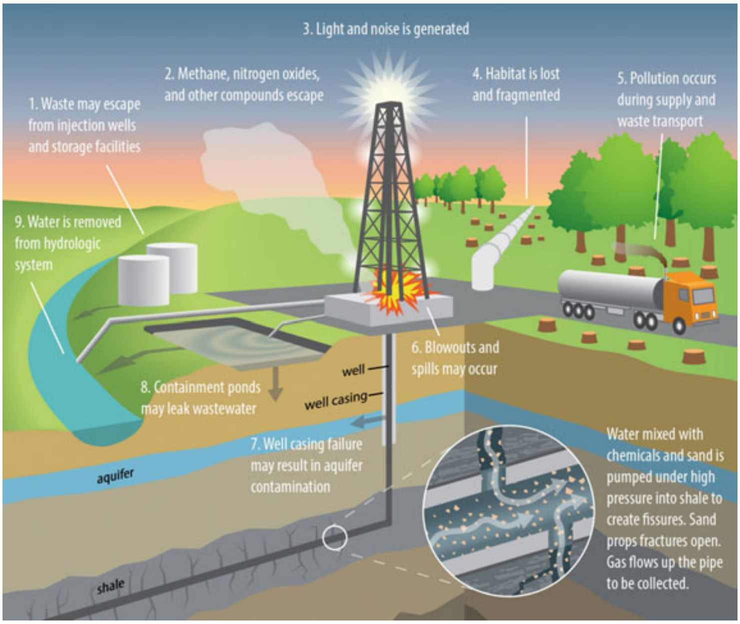

Fig. 1 Environmental problems related to shale gas production (*Source*: http://wws.princeton.edu/sites/default/files/content/images/news/Figure2_Souther.jpeg)

Fig. 2 The ecological impact from shale gas extraction operations on the landscape (Wyoming's Jonah Field, USA) (*Source*: https://blogs.princeton.edu/research/files/2014/07/2014_08_01_Souther_TingleyFREEPressRelease_Photo-500x361.jpeg)

non-shale formations. Penetration into such formations of fluids containing chemical agents will increase the polluted area.

The fracking envisages injection of water containing sand and proppants under a pressure of 500–1,500 atm into gas bearing formations, as a result, cracks are created through which gas flows into the well. The fluid injected into the well contains coarse sand to prevent closing of cracks after pressure drop.

In coal mining, the risks affect primarily those who directly participate in this process, i.e., coal miners, while the potential risks associated with fracking involve environment contamination and negative impacts on human health far from the place of works. Therefore, the implications of the accident during fracking may be comparable to those occurred as a result of accident at the nuclear facility [3].

The main reasoning of ecologists is that after stopping the extraction the hazardous chemical agents that even include radioactive isotopes may get with fluid into subsurface formations. This is fraught with contamination of reservoirs used for drinking water supply of the densely populated northeast of the USA.

3 Impact of Shale Gas Production on Water Resources

The fracking technology requires much water in the vicinity of the developed play as well as significant amounts of sand and proppants added into it. The problem of obtaining water resources is quite acute. In many countries, the water resources are limited and there is water deficit. The European countries do not have free great volumes of water required for fracking and they have no service companies. As a result, the well drilling and play infrastructure development are fourfold costly than in the USA. Moreover, the fracking technology requires availability of ample water resources nearby the plays as one fracking operation uses 1,000–7,500 tons of water of which 30–50% remain underground, while the remaining amount is pumped by submerged pumps. Consequently, considerable volumes of water are accumulated for which storage extensive land areas are required [4].

Different chemicals are added into fluid to reduce its viscosity and corroding action and to prevent deposition of mineral salts on tube walls. The reagents permanently added into water may get into groundwaters and cause serious hazards. The shale gas production generates toxic water.

The fluid used for fracking in shale gas plays is the water with the minimal required additives accounting for 0.5% and sometimes to 2% [5].

One fracking operation in horizontal wells requires around 4,000 tons of water and 200 tons of sand. On the average, three fracking operations are conducted on each well during 1 year. Thus, the total water requirement reaches 12,000 tons.

Shale gas production causes contamination of subsurface waters as fluids through cracks created by fracking may get into the nearby water aquifers and from there into the formation. At deep occurrence of shales, the probability that the remaining fracking fluids may reach the ground surface is very low; however, at not deep occurrence of formations such probability becomes greater [6].

Shale gas extracted in several states in the USA made drinking water there toxic (Fig. 3). Similar instances of water contamination were witnessed in Colorado, Texas, and West Virginia. The issue of the shale gas impacts was discussed in the US Congress. The authorities of the New York state were the first to impose moratorium on shale gas production. This happened in 2010 after warnings of experts on hazardousness of the hydrolytic extraction technology assuming injection into the shale rocks of great amounts of water with special chemicals added into it.

Based on the Clean Water Act of 2005, the ecologists succeeded adoption of the ordinance obliging shale gas companies to make public the formulation of chemical additives and to reduce the chemical load on the region's environment.

Fig. 3 Burning of drinking water as a result of shale gas seeping into aquifers (*Source*: https://i.ytimg.com/vi/4LBjSXWQRV8/maxresdefault.jpg)

The Quebec's environmental bureau report (Canada) contains recommendation to stop completely the shale gas projects until the additional investigations are conducted. The scientists assert that the shale gas extraction is fraught with the risk of contamination of drinking water sources.

4 Impact of Chemical Agents on Natural Environment

The commercial production of any natural deposits invariably produces the increased technogenic impact on the natural environment. The chemical solutions used in fracking are highly toxic. Much anxiety is stirred by the state of local drinking water wells and underground water aquifers. Ecologists assert that during shale gas extraction such chemical substances as toluene, benzene, dimethylbenzene, ethylbenzene, arsenic, and others find their way into groundwaters. Some companies use hydrochloric acid solutions thickened with polymers. One fracking operation requires 80–300 tons of chemicals. This gives rise to serious environmental concerns. In particular, there are no adequate capacities to treat the whole volume of wastewaters. But even treated mud solution is capable to contaminate significantly the groundwaters and the more so as only a part of wastewaters is lifted from wells. Benzene, arsenic, and radioactive materials will be pumped to the surface from shale formations. The most successful shale plays occur in the Paleozoic and Mesozoic rocks and feature the high gamma-radiation level which correlates with the thermal maturity of the shale deposits. Consequently, fracking radiation penetrates into the top layer of sedimentary rocks; hence, the high radiation background is witnessed in the shale gas production areas.

Chemical agents used in fracking to ensure the required viscosity of injected fluid are carcinogenic and their getting into the artesian aquifers used for drinking water supply will be disastrous (Table 1).

The cracks formed during fracking (their length reaches 150 m) may spread to the overlying formations. More than that, these operations are practically always accompanied by inflow of waters from the upper horizons. This leads either to contamination of groundwaters with injected fluids or penetration of shale gas found in artesian wells into them. It was found about 500 different chemical compounds which toxicity and stability in deep-lying horizons have not been adequately studied so far.

Fracking is conducted much lower than the groundwater level. However, the soil, groundwaters, and air become contaminated with toxic substances. This occurs by seeping of chemical substances through cracks formed in the sedimentary rocks into the topsoil layers. In addition, this technology involves the discharge to the surface of great volumes of contaminated water that should be pumped out so that it does not penetrate into the local drinking water sources. The main environmental concern is the possibility of contamination of water bearing formations with methane and applied solutions.

Table 1 Standard additives in the fracking fluid (for Cotton Valley and Travis Peak plays in Eastern Texas) [7]

Additive name	Additive type	Concentration
10% FE acid	Acid/solvent	1,000–3,000 gal prior to fracking
BA-40L™	Buffer solution	0.5–2.5 gal/1,000 gal
BE-9	Biocidal agent	0.25–0.5 gal/1,000 gal
CL-23	Crosslinked linear polymer	0.2–1 gal/1,000 gal
Common White Sand 100 mesh	Proppant	0.1–1 lbs/gal
FR-66	Friction reducing agent	0.2–1 gal/1,000 gal
Gas Perm 1100	Surface active substance	0.5–10 gal/1,000 gal
HAI-404M™	Anticorrosion agent	5–25 gal/1,000 gal
LGS-36UC	Gel liquid concentrate	2.5–6 gal/1,000 gal
PRC Premium Sand 40/70 mesh	Proppant	2–3 lbs/gal
Premium White Sand 40/70 mesh	Proppant	0.5–2 lbs/gal
ViCon NF	Fracking gel thinner	1–10 gal/1,000 gal

Shale gas that was not trapped by wells rises to the surface with the injected chemicals seeping through the soil, thus, polluting groundwaters and the fertile soil layer.

Such risk appears at any breaches of the well construction technology. To avoid this, the company uses at minimum 2–3 casings with subsequent grouting. For gas recovery, it is necessary to pump out fracking fluid from the production well. Water, even technical, is a mineral deposit that should be paid for. Therefore, to cut the costs the pumped out fluid is collected in special pits from where it is recycled to hydraulic fracturing. It is at this stage that the threat of environment pollution appears, and not of groundwaters, but of soil layer or surface water streams [5].

Fracking fluids contain many hazardous substances. There is about a hundred of the applied chemical additives, including, among others, volatile organic compounds (toluene, cumene, etc.), carcinogenic agents (benzene, ethylene oxide, and formaldehyde), mutagens, and other substances affecting the human endocrine system, as well as stable and biologically accumulated pollutants. In the course of shale gas extraction, water is contaminated with methane and radioactive substances that are washed out from rocks covering plays.

Technological risks are connected with reliability of water tightness of all horizons penetrated during drilling. This is most essential for underground (artesian) aquifers passed through during well construction. Apart from this, there is also a danger of pressure rising to the level of destructing not only shale rocks, but also nearby formations [8]. This requires development of the environmentally friendly chemicals and reagents.

5 Legal Support of Shale Gas Production

Different countries have their own legislations regulating shale gas production. The greatest experience in this field is amassed by the USA that has developed legal acts on the federal level and on the level of individual states regulating the issues of shale gas prospecting, extraction, preparation of infrastructure, ecology, and relations with the population living in the vicinity of drilling sites. Thus, the USA has the National Environmental Policy Act containing requirements to exploration and production of mineral deposits. The US Department of Interior Bureau of Land Management issues permits to fracking application. The USA has also the Clean Water Act regulating the wastewater disposal. Apart from the above, there are also documents imposing restrictions on atmosphere pollution, getting of hazardous chemical substances into water resources and soils.

In individual states, the exploration, production, and environment protection are regulated both by federal laws and by specific legislation. At the same time, all US states should have legislations issuing separate permits to drilling and other operations connected with works on drilling sites. Moreover, some states passed laws obliging companies to disclose the information about chemical reagents.

Regardless of availability of numerous laws, both on the federal level and on the level of individual states, the USA failed to resolve all problems related to nature conservation. And the main reason for this is the influence of political and energy factors connected with endeavors of the US authorities to reduce dependence on oil and gas supply from other regions.

Europe started addressing the issues of environmental legislation related to development of shale plays only in the early second decade of this century. Most active in this respect is Poland that was one of the first European countries to start practical implementation of shale projects. In Poland, these issues are in the competence of the Ministry of Environment that together with the Department of Geology and Geological Concessions issues permits to shale play development. However, the country has no specific legislation. Thus, the shale gas issues are regulated by the geological and mining law passed in February 1994 [9].

In Poland, the lands around wells are privately owned by small landlords who potentially restrict production. In addition, the shale development in the European countries is restricted by environmental considerations and the cost of shale gas production is twice higher than in the USA.

The European legislation has its specific features preventing shale gas production in the same manner as in the USA. In the USA, the landholder also owns the land interior and receives income from the resources contained therein, while in many European countries the land interior is in the ownership of the state and any charges should be paid to the state. There is no reliable and detailed geological investigation of production areas in Europe which makes difficult the assessments of unconventional gas resources. The European environmental legislation does not permit development and production of these resources for considerations of hazards to the natural environment [10]. Besides, the first attempts to drill for shale gas in

European countries increase the public pressure on the governments of these countries to stop shale play development.

In densely populated Europe, this may become a serious obstacle for implementation of shale projects due to the EU stringent environmental regulations. For launching drilling works, it is necessary to have the norms ensuring safety of works and protection of groundwaters. Some components added to attain the required viscosity of fracturing fluid are carcinogenic, therefore, their getting into groundwaters is dangerous. Besides, fracking cracks may develop upwards contaminating groundwaters with injected fluids or facilitating the ingress into them of methane.

France was the first European country that adopted the law banning the shale gas production. On June 30, 2011, the French Parliament voted for the ban of hydraulic fracturing due to likely threat to the environment. The works were stopped upon insistence of ecologists. This was a decisive step of the Parliament members who after studying the US experience in shale gas production expressed their doubts whether the fracking technologies were environmentally friendly. The main hazard was considered to be the horizontal drilling that envisages injection of water into cavities containing gas, thus, forcing it out to other wells. Here the walls between separate cavities in shales are broken down by hydraulic fracturing which, under unfavorable circumstances, may cause large downfalls or flooding of territories. In the USA, shale gas is extracted in sparsely populated areas, but in Ukraine and Poland the situation is quite different. Even without shale projects, Ukraine abounds in territories with enormous underground cavities formed as a result of coal and iron ore mining.

The French association of oilmen declared that it disapproved the decision taken by senators. However, considering the negative attitude of the public to shale projects that was shaped mostly with regard to the ecologists' opinions and also the high cost of such projects it can be said that in the near future the commercial development of shale gas resources in this country is quite unlikely.

Moratorium on shale gas extraction was also imposed in Germany and in Lower Saxony and North Rhine – Westphalian. However, in 2014 Germany declined the complete ban of the fracking technology.

Britain generally supports the shale projects, but does not go beyond political declarations. The reason for such cautious attitude to shale issues of the British government is that the main shale plays in this country are found in the shelf area and their development is still economically unsound.

In April 2012, the EU Parliament conducted hearings at which it was stressed that the shale gas production technologies meet the current environmental regulations. Accordingly, regardless of any negative factors, primarily, related to environment, many countries are not going to abandon the shale projects. For example, Poland advocates the adoption by the EU of the legal acts supporting the shale play development.

In September 2012, the Committee on the Environment, Public Health and Food Safety of the European Parliament passed the resolution stating that the shale oil and gas production in the EU territory should strictly comply with the environmental standards. In November 2012, the EU Parliament authorized shale gas extraction in the EU countries and did not support the proposal to impose moratorium on the application of fracking technologies.

6 Effect of Hydraulic Fracturing on Subsoil

In the shale gas projects, the application of fracking technologies may enhance the seismic risks and lead to earthquakes. It is thought that fracking technologies caused two small tremors near Blackpool, the seaside resort in Lancashire, Britain. The first tremor was registered on April 1, 2011 with the magnitude of 2.3 by the Richter scale, and the second with the magnitude of 1.5 occurred in May 2011. A similar incident was earlier recorded in the Ohio state in America.

The US Seismological Service did not record in this country any large earthquake that could be connected with gas extraction from shales. It is thought that only in rare cases the fracking can directly cause earthquake with the magnitude not more than three points. But this issue requires further investigation [11].

It can be said with high enough probability that fracking operations could cause small tremors due to an unusual combination of geology factors at the well site coupled with the pressure exerted by water injection as part of operations. Such combination is extremely rare. And although currently the relationship between fracking and underground tremors has not been investigated properly, in the production areas we can still witness land subsidence. Regardless of these facts, Britain is not going to abandon completely the shale projects.

In the USA, there were already scandals connected with breaching the rules of hydraulic fracturing by major service companies. In March 2011, the US President ordered to create the Shale Gas Subcommittee within the frame of the Advisory Council at the Department of Energy. The report prepared by this subcommittee contained nine recommendations on the issues arousing major concerns. First of all, it related to the likely water and air contamination and degradation of living conditions in the territories located nearby the shale gas production sites. Special attention was also focused on the negative implications for settlements and ecosystems in the shale project areas [12].

The moratorium on hydraulic fracturing has been imposed and still operates in Pennsylvania and New Jersey in America. The shale gas production was suspended in Quebec and Alberta provinces in Canada. Quite recently, the legislators approved restrictions on shale drilling in Maryland, Pittsburg, and Buffalo. The moratorium should remain in force till the scientists confirm that there is no negative impact of hydrolysis on the natural environment and drinking water sources. Similar decisions are being prepared in Ohio and West Virginia.

In some drilling sites in Pennsylvania, some alien substances were found in soil, rivers, and groundwaters. Controlling bodies have fixed more than 250 facts of breaching the local norms concerning operation of treatment facilities and safe storage of waste additives. Based on judicial and administrative rulings, the activities of many shale gas companies in Pennsylvania were stopped. Experts also stress the problem of greenhouse effect caused by methane leaks during shale gas extraction [13]. The greenhouse gas emissions into the atmosphere of shale gas projects are much greater than at traditional extraction [14].

The US scientists declared about the negative impacts of chemical agents used in hydraulic fracturing on human health, but when great profits are at stake they try to neglect such factors. Thus, the issue of the “shale miracle” is used for brain drain of not only ordinary public in America, but in other countries, too. The USA makes attempts to export the respective technologies to Europe. In that they pursue not only economic benefits, but also their political targets – to reduce energy dependence of European countries on traditional gas suppliers, primarily, Russia.

Human right activists call to ban the shale gas production in the USA and Britain as this may lead to disastrous consequences in these regions and will leave the greater part of the population without pure drinking water. Taking into consideration that the shale gas extraction requires more than 100 times greater number of wells than for extraction of traditional gas, the US public expresses great concerns about the likelihood of wide-scale contamination of groundwaters.

7 Seeking New Technologies

The leading petroleum and gas companies have conducted researches to alleviate the negative impacts of shale gas production suggesting alternatives that will substitute water required by fracking technologies. Thus, the Japanese research group of the Kyoto University suggested using carbon dioxide instead of water. The Canadian Company GasFrac has developed a new technique of shale fracturing with injection of propane-based gel instead of water.

Company Halliburton took a different way suggesting new method of water treatment. The CleanWave technique supposes treatment of fracking water with the help of positive ions. At the same time, the company proposed one more option – application of membrane distillation when the wastewater is recycled without mixing with freshwaters. Company Novas Energy USA suggested the plasma pulse technology (PPT) when the horizontal wells are “blown through” not with water, but with electrically generated plasma impulses [15].

The search of new technologies capable to substitute water resources or mitigate the fracking consequences goes on. However, while the world still has considerable resources of traditional gas, the shale gas most likely remains the strategic reserve that may produce its global effect in the far perspective.

8 Conclusions

In May 2011, Britain published the report of the House of Commons of the British Parliament and the Energy and Climate Change Committee saying that the shale gas resources available in Britain will quite unlikely influence cardinally its power supply. Senior analyst of European gas and LNH markets at Société Générale T. Bros, the author of the book "After the U.S. Shale Gas Revolution," in his interview said that Britain had already come to an understanding that shale gas could bring profit through rivalry and revenues. He also added that it was already quite clear that no shale revolution would occur in Europe. In Britain, the shale gas production may become more real by 2020 when some positive results were attained. At the same time, this document stressed that the government of the country should track closely the changes in the shale gas development in Poland as this information was very important in terms of future plans and adjustments to be made in the national and European legislations with further progress of the situation in this area. But the key issue of this report is that its authors did not support moratorium on the fracking technology application while developing hydrocarbon resources in Britain, believing that the shale gas extraction had no negative environmental impacts.

The public concerns in some European countries in respect of environmental risks urged the EU to have a closer look at this issue. In the early 2014, the European Commission approved the recommendations on environment and climate protection while applying hydraulic fracturing in shale gas extraction. These recommendations were called to assist the EU states intending to apply fracking technologies in shale play development with management of environmental risks [16].

It follows from the above that the shale gas cannot not be considered the alternative of the natural gas, because its extraction fails to meet the modern stringent environment safety requirements to the commercial scale development of plays in many world countries. The prospects of shale gas production are available only in the sparsely populated areas and in the countries that are ready to sacrifice environmental safety for extraction of this hydrocarbon. In addition, the limiting factor of commercial shale gas production is also the high cost of its extraction.

The technology of shale gas production and environmental implications of its application have already roused protests in many countries. Ecologists stress that in endeavoring to increase the scales of shale gas production many global issues faced by whole regions are neglected. One of such issues is the shortage of water resources required for fracking. By different forecasts, by 2025 the planet will face the water crisis and in this context the shale gas production seems a suicidal idea.

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Conclusions

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Abstract This book highlights the problems of the shale gas production that influenced greatly the situation in the global gas market. It brings into focus such issues as production technologies, environment protection, and impact of the consequences of the shale gas production on a man. The book also investigates the role of shale gas in development and implementation of foreign policy of many world countries that welcomed the possibility to organize production of this hydrocarbon in their own countries. Taking into consideration the information published by world energy research centers, the prospects of the shale gas production in different regions of the world are studied. This book seeks to integrate such issues as shale gas production, politics, technological development, and ecology. It will be of use for the specialists in the area of hydrocarbon production, international relations and foreign policy, world economics and technologies, and ecology and environment protection.

Keywords Ecology, Hydrocarbons, Production, Reserves, Shale gas

Content

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Fig. 1 Diversification of the gas development (http://www.mining.com/wp-content/uploads/2012/12/PetroChina_Alberta_shale_gas_Encana.jpg)

The beginning of the twenty-first century was marked by fundamental changes in the energy sphere. Production of the shale gas being a variety of the natural gas extracted from shales – the sedimentary rocks with high content of organic matter – produced most significant influence on development of the global gas market. Accomplishment of shale gas projects has become the goal for oil and gas companies as well as a part of the state policy of many world countries. Development of shale plays is targeted to attain energy independence (Fig. 1).

The first efforts on shale gas production were made in the nineteenth century in the USA. That time, the commercial shale gas extraction has not evolved due to inadequacy of technologies. But the efforts in this direction went on and the technologies of shale play development were constantly improving.

The cardinal changes in the shale gas production were witnessed after development and introduction of the revolutionary hydraulic fracturing technology which permitted to increase the shale gas production. By using chemicals and the new method of horizontal drilling when the bore gradually deflates from the vertical to 90° and continues moving parallel to the ground surface, the oil and gas companies managed to increase significantly the recovery of shale gas.

However, the breakthrough in shale gas production occurred in the mid of the first decade of the twenty-first century when the technologies were improved so as to ensure commercial scale production. That time, the term “shale revolution” appeared. The US success drew attention of many countries that started considering this factor in development of their own energy strategies. In 2009, the USA left behind Russia by the natural gas production: 624 bcm in the USA against 596 bcm in Russia. This became possible owing to the shale gas whose fraction had been gradually growing in the total gas production. At the end of the first decade of the twenty-first century, the information started appearing about the enormous shale gas reserves found in the Netherlands, Poland, France, Sweden, Austria, Britain, Hungary, Germany, and Ukraine.

Availability of the immense shale gas reserves permitted the USA to secure its leading positions and to have strong influence on formation of the global gas market. In 2013–2015, the USA demonstrated the high rates of shale gas production that exceeded 300 bcm. In the past years, the shale gas production in the USA had risen more quickly than it was expected earlier and this led to the abrupt drop of the spot prices in the American continent and in Europe.

The commercial shale gas production in the USA forced Canada, China, and Argentine to launch shale play development. Despite considerable expenses and state support in these countries, the volume of the shale gas production was meager [1]. As a result, the USA remains the only country producing significant volumes of unconventional hydrocarbons. By 2030, it is expected that in the USA the shale and coal gas will account for 63% of the total gas output. According to projections of the International Energy Agency, by 2035 this figure will be as large as 71% [2].

Unlike the USA where the shale plays have been surveyed for several decades, other world countries have no accurate assessments of the reserves of this hydrocarbon as they have no reliable methods to determine the volume of gas-bearing shales; consequently, all data about shale gas reserves in different world regions are only rough specifying the potential resources of shale gas.

In the recent years, the situation has been changing. The investigations of shale gas reserves were initiated in many countries. As a result, the new, verified data about reserves of this hydrocarbon were published. This information is required, first of all, by oil and gas companies that are ready to take risks and invest money into development of shale plays.

The phenomenon of the "shale revolution" promoted by the US companies was not neglected in energy dependent Europe. The US experience and success in shale gas production stirred great interest in many European countries that initiated development of projects on recovery of their own reserves of shale gas and oil. These European countries were seeking to diversify the sources of hydrocarbons supply and to lower their price.

Many European countries have to acknowledge that they have no accurate data on the shale gas reserves, no adequately developed infrastructure, and they have no qualified personnel and technologies, too. At the same time, the movement of ecologists speaking against shale gas production due to its negative impact on the natural environment was expanding in Europe. The European countries believed that with the help of the shale gas they would attain energy independence.

The major oil and gas companies that in 2009 rallied their efforts promoted the projects on shale gas production and shale surveys in Europe. They are Statoil, ExxonMobil, Gas de France, Wintershall, Vermillion, Marathon Oil, Total, Repsol, Schlumberger, and Bayerngas.

The growth of the shale gas production in the USA drew more attention to the shale gas issue in Europe. In 2012, the European Parliament permitted the EU countries to extract shale gas and did not support the idea of moratorium on the fracking technology application. At the same time, the policy of European countries in respect of the shale gas prospecting and development was differing; they had no single position in this matter. The European countries proceeded from their own interests and assessments of opportunities for shale play development. Moreover, in united Europe there was no single strategy towards such technology of gas production [3].

The European countries like many other states that showed interest to the shale plays had to acknowledge that there were no accurate data about these hydrocarbon reserves. This encouraged many speculations concerning the shale gas reserves giving rise to fantastic projections about the future production volumes. Consequently, Europe has no accurate data about the shale gas reserves, but only rough assessments varying within a wide range.

Difficulties connected with the shale gas production in the absence of the verified information about its reserves and the associated environmental risks may also force to postpone the commencement of shale gas production in Europe to uncertain perspective. Consequently, it can be said that even in case of growth of the shale gas production the prices of this hydrocarbon in Europe will not drop so quickly as in the USA. Accordingly, the long waiting for development of the shale gas production will create prerequisites for maintaining high interest in Europe to further development of pipeline transport and to supply of liquefied natural gas.

The effect of the "shale revolution" in different European countries will vary widely and will be determined by such factors as the national energy strategy of a country, the degree of its dependence on energy import, forecasts of the gas demand growth, the cost of alternative competing energy deliveries, and the attitude of the population. However, this effect may be decisive for small and medium independent companies whose business is oriented to the emerging shale gas industry in Europe. Therefore, the pace and feasibility of shale play development in Europe will depend on numerous factors, including environmental and social, energy prices, demand for gas as well as the taxation and regulation regimes.

One of the first European countries that have shown interest to shale gas production is Poland. According to preliminary estimates, Poland possesses considerable reserves of this hydrocarbon. The stimulus to assess shale gas reserves here appeared after commencement of its commercial production in the USA. The interest of Poland to the shale play development was enhanced by the dependence on Russian gas. Poland was the first in Europe to initiate surveys of shale plays and launching projects on shale gas production. The Polish authorities were forced to take such steps in view of the gas production drop in the country and stopping of prospecting of new fields.

In 2008–2009, Poland initiated the program of investments into development of large gas fields in dense rocks. It was expected that the Polish "shale revolution" supported by the US corporations would permit to increase the gas production from 5 to 109 bcm and even more [4].

The shale gas production was named by the Polish authorities as the priority direction in the energy policy. Poland believed that the shale gas reserves in the country might be much greater than in the USA as the geological conditions in Poland were much better than in US plays. This fact allowed for an assumption that the shale gas would free Poland of its dependence on the Russian gas.

In 2013–2015, Poland failed to make a breakthrough in shale gas production. Although considering it the key issue for ensuring the energy security, Poland, like many other European countries, faced such problem as a high cost of shale gas production due to complex geographical conditions in its territory. This makes the shale projects in Europe more costly than in the USA and does not permit to expect the obtaining of additional volumes of shale gas in the nearest decade.

The implementation of shale projects in Poland encountered numerous problems: high cost of geological prospecting and extraction works, inadequate knowledge of shale plays, and lack of technologies. Poland also had to create the pipeline infrastructure. To attain the target of the shale gas production around 6 bcm per year by 2025, it will be necessary to invest 11 billion USD and further on to spend up to 1.5 billion USD each year for production increase by 2035 [5].

Great interest to the shale gas was shown also by Hungary and Bulgaria considering it as an additional source to satisfy the needs of their economics in this hydrocarbon. However, the inadequate geological study of shale plays did not permit these countries to launch commercial production. Recently only plays containing potentially significant reserves of shale gas have been surveyed.

The European countries face high cost of shale hydrocarbon development due to complex geographical conditions in their territories; thus, the cost of shale projects in Europe is much higher than in the USA. There are several factors that obstruct successful implementation of shale projects: complicated geological conditions, high population density, tough environment protection regulations, insufficiency of financial stimuli, and tax privileges. As a result, the shale gas may play its role in Europe not earlier than in 5–10 years [6].

The development of shale gas production in Europe is hold back by some factors. The shale plays in Europe are only in the early stage of development and have not been studied adequately in terms of geology and cost of extraction. In addition, the development of shale plays leads to disturbance of the bowels of the earth and pollution of water aquifers with chemicals used for hydraulic fracturing. The cost of shale development in Europe may be 4 times as high compared to the USA [7]. And, at last, the activities of ecological organizations restrain the promotion of the shale gas development projects in European countries. Consequently, the shale gas may become attractive for European countries in the future provided that the production costs are reduced and the efficiency of shale play development is improved.

The shale gas production in the USA drew attention of China that, like many other world countries, possesses considerable shale gas reserves. However, China has no accurate data on shale gas reserves, there are only rough assessments that vary greatly. Nevertheless, many researchers agree that China has immense shale gas reserves, but their development involves many difficulties.

In 2011, China officially recognized the shale gas as the independent hydrocarbon. During 2011–2015, China made serious efforts to develop the commercial scale production of shale gas so as to reduce the dependence of the country on gas import from Central Asia and other world regions.

The efforts of China to develop shale plays were not missed in the USA. The American companies were endeavoring to circulate as wide as possible and to resale the technologies of shale gas production. These issues were discussed during the visit of US President B. Obama to Beijing in November 2009. As a result, the

USA and China concluded the framework agreement, the key issue of which is provision of the US technologies to China to develop its shale plays [8].

The issues of feasibility of the shale play development are being actively discussed in the countries exporting natural gas to foreign markets. One of these is Russia. After the USA has increased considerably the shale gas production, the interest to this problem in Russia has also grown, but it came to nothing more than discussions in the expert community as availability of immense natural gas reserves makes shale gas less attractive [9]. And the more so as the production cost of traditional gas is much lower than the expected cost of shale gas [10].

No endeavor to organize the commercial scale production of shale gas may be attributed to the absence of accurate data on the available shale gas reserves in the territory of Russia, high costs of production, and high environmental risks. Moreover, there are no appropriate technologies, which brings up the question of improving the efficiency of enterprises in the gas industry [11].

Regardless of the lack of interest in Russia to shale gas production, the Russian authorities have to take into consideration the effect of the "shale revolution." The greatest risks are connected with shale gas development in Europe especially as the European countries view the shale gas development as one of the alternatives of the Russian gas. Moreover, Russian company Gazprom faces the growing supply of liquefied gas and drop of demand for gas. This forces Gazprom to adjust the prices of the gas exported to the European market. Taking into consideration the pace of progress in the shale gas production in Europe, the Russian gas will remain for long one of the main hydrocarbon source for the European countries. But the key issue will be the price by which Russia will supply its gas to the European market. In any case, the shale gas production in Europe and its deliveries from the USA will cut down the segment of Russia in the Europe market [12].

The quick rise of the shale gas production in the USA affected significantly the global energy markets. This is connected, primarily, with the sharp curtailment of the natural gas import to the USA. In addition, the scenario of the US shale gas import to the European market that was found under great pressure of the "shale revolution" has been actively discussed recently. Other countries possessing shale gas reserves are also developing plans to increase shale gas production. Although the first results of export of the "shale revolution" have shown that the US experience would be quite unlikely repeated in the next decade, but still influenced by the growth of the shale gas output the global energy market is already changing immensely. Moreover, the growth of the shale gas production has already its geopolitical consequences playing the key role in weakening the opportunities of Russia to use its "energy weapon" against its European users by increasing alternative deliveries to Europe in the form of LNG forced out from the US market [13].

Apart from this, the USA has not abandoned the plans to supply the shale gas to the European market. Still in 2014, the US gas was not the cost-effective commodity for the European Union, but as the prices of natural gas are tied to the dropping prices of oil the purchase of shale gas has become feasible regardless even of its transportation across the Atlantic. The first gas-loaded vessel from the USA was dispatched to Europe in March 2016.

The degree of influence of the shale gas in different regional markets will vary significantly in view of the unique features of each of them. This may lead to considerable geopolitical changes that will affect the world politics. At the same time, it is too early to speak about the decreased role of hydrocarbons supplied via pipelines. The availability of considerable oil and gas reserves, developed infrastructure, and availability of effective technologies are still important factors making the pipeline transport vital.

The shale resource development is closely connected with the issues of food security and water resources. These three issues are so closely intertwined that their solution requires an integrated approach and long-term planning by many states [13].

The shale gas production forces to make adjustments in the foreign policy of many countries provoking new lines for rivalry and cardinally changing the alignment of forces in the global and regional energy markets. The production technology of shale gas the reserves of which are found in many countries that have not earlier entered the gas producer pool may change cardinally the situation. And the more so as many world countries, primarily, main producers and users of hydrocarbons, are involved in the process of shale gas production.

Many countries view the shale gas production as the sole alternative to the Russian supplies. In particular, Moldavia is very vulnerable in terms of natural gas supply. Russia is the only source of natural gas for this country. Diversification of energy supply may form prerequisites for lowering the gas prices, thus, creating rivalry to the Russian gas. However, such scenario may be realized in the far perspective. At the same time, Moldavia takes into account the negative environmental consequences of the shale gas production and is not in a hurry to spur the extraction of this hydrocarbon.

Ukraine is facing similar problems and attempting to address them as the energy independence is the priority goal for this country. One of the directions of this policy is development of new fields of hydrocarbons, in particular, of unconventional gas (shale gas, coal methane, tight gas reservoirs, etc.). However, the first attempts of Ukraine to develop domestic shale plays, including with invitation of the leading oil and gas companies, have failed. High political risks, lack of accurate data on the shale gas reserves, and lack of infrastructure played their role here.

The issues of shale gas production are also acute in Kazakhstan. But the inadequate geological study of potential shale plays, lack of legislation that will control the development process, high environmental risks due to imperfection of production technologies, and also high investment risks of shale projects obstruct, to a great extent, the implementation of this strategy oriented to shale gas recovery in Kazakhstan. But this does not mean that the country will not take attempts to develop the shale gas production.

The shale gas production in the USA not only enhanced the interest to seeking the alternative to pipeline gas, but stirred greater concerns about the consequences that will arise in the course of shale play development (Fig. 2). Primarily, these are environmental concerns. A breakthrough in shale gas production led to the growing negative impact on the natural environment and human health. Here the key issue is application of the hydraulic fracturing technologies. Investigations have shown that

Fig. 2 Shale gas development (https://www.irgc.org/wp-content/uploads/2014/02/iStock_ShaleGasLarge1.jpg)

fracking causes serious changes in the geological structures, ground and surface waters, atmospheric air, soil, and earth conditions. Moreover, the negative effect is produced during preparation for shale gas recovery which is connected with the need to create the required infrastructure. All these factors urged the public to organize movements against the shale gas production. The ecological organizations are most active in the European countries where the consequences of the commercial shale gas production will be more extensive. For this reason, the EU is seeking to develop recommendations for protection of the environment and climate for application of fracking technologies in order to minimize environmental risks [14].

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