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Does Russian unconventional oil have a future?

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Abstract
Russia is estimated to hold the world's largest technically recoverable shale-oil resources. The conventional oil resource base is still very large, but there are doubts about how much is economically recoverable. Increasing attention is given to unconventional oil. The purpose of the article is to assess whether fundamental conditions for sustainable, profitable production of unconventional oil are in place. Compared to the successful development of unconventional oil in the USA, Russia has several disadvantages. The Russian oil sector is dominated by big companies without the flexibility in methods and decision-making required in very heterogeneous unconventional projects. Infrastructure is less accessible in Russia than in most American projects. On a more fundamental level the relatively poor condition of geological data collections is a serious cost increasing factor, and the system for development and dispersion of new technologies has critical shortcomings. Russia lacks appreciation of risk taking and a corresponding regulatory framework, as well as relevant financial mechanisms. Nevertheless, government documents almost exclusively focus on technology as such as well as on taxation and tax benefits as preconditions for successful development. Without addressing the fundamental institutional problems, the potential for exploiting the resources base will be limited.

Keywords: Russia; shale; oil; unconventional; resources; Bazhenov.

1. Introduction

The production of shale gas started in the USA in the 1990s on an experimental basis. From 2005 to 2014 its share of USA's output grew from almost zero to 40% (Pumphrey, 2015), and by 2009 the USA had become the world's largest producer of gas (BP, 2017). Just a few years after shale gas emerged on the scene, a similar development got underway with oil. From 2010 to 2014, American oil production soared, reaching 519.9 million tons[1] – an increase of 60%, made up almost exclusively of tight (including shale) oil, which is oil held in rock formations – in this article jointly referred to as shale-oil. By 2015 the USA had the same output as Saudi Arabia, the world's top oil producer. There has been some discussion of whether such high output levels are sustainable (Hughes, 2013), but little disagreement that 'the shale revolution' in oil and gas production is here to stay (Morse, 2014).

The re-emergence of the USA as the leading energy producer, with the addition of so much new production capacity, has rattled world energy markets – and constitutes a major challenge for many traditional petroleum producers (Auping et al., 2016). This 'revolution' has been taking place in the USA, but the natural conditions for unconventional production are in place also in many other countries (see Table 1). Exploiting these resources is no straightforward matter, however, and there is disagreement over how much of the potential will ultimately be commercially, regulatory and politically exploitable (Lozano Maya, 2013). A case in point is Russia, which, according to USA Energy Information Administration estimates, holds the world's largest technically recoverable resources of shale oil, as well as considerable reserves of unconventional gas (EIA, 2013).

Russia was until recently the world's top producer of hydrocarbons, but there has been growing concern about its ability to uphold oil production because its conventional resource base is being depleted and new fields are smaller, more complicated and remotely located – thus more expensive to develop (Kryukov and Moe, 2013a). With Russian gas, however, there are still ample, accessible conventional resources.

Table 1. Top 10 countries with technically recoverable shale-oil resources (billion barrels)

- About here –

The search for regions that can replace production from the large fields now on the decline has been a major issue in Russia. Much has been expected of Eastern Siberia and, more recently, the Arctic offshore. In both cases, an important argument has been that opening new regions would permit the Russian oil industry to continue using well-known methods and to run large-scale projects, although offshore would require heavy contributions from foreign companies. The presence of shale-oil resources has been known for some time, but without attracting much interest – probably because of the country's ample conventional resources, and because exploiting unconventional resources would differ radically from the traditional approach of the Russian oil industry. Some projects are now underway, with interest spurred by attention from foreign companies, as well as by developments in the USA. Therefore, we ask: how promising is the outlook for developing untraditional oil in Russia?

Experience gained with unconventional hydrocarbons in the USA offers a

[1] Throughout this article volumes are reported in tons to preserve the original data from Russian sources where metric tons is the standard measurement, except where original data are in barrels. Conversion factors are not unequivocal. For instance, BP and Gazprom uses a factor where one metric ton of oil equals 7.33 barrels, whereas Rosneft uses 7.46. The factor will vary according to the type of crude oil.

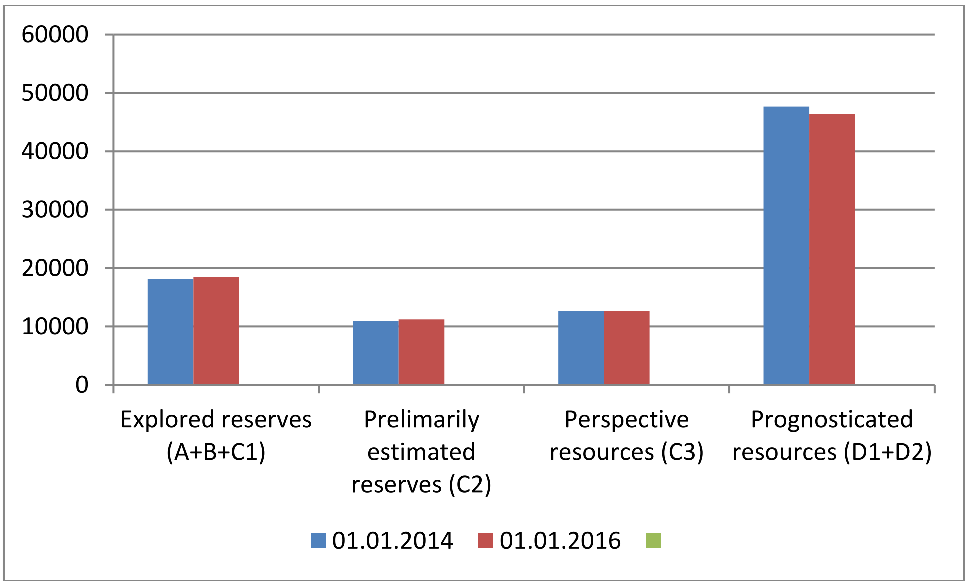
natural point of departure for discussing the prospects in Russia. Obviously, there are major differences in the industry between the USA and Russia – but are they of a character and magnitude that could seriously limit the potential for developing unconventional oil in Russia? It is also relevant to examine the characteristics of unconventional resources as such. What distinguishes unconventional from conventional resources? How do unconventional resources fit in with the general development of the Russian hydrocarbon resource base? Does Russia have its own approach to developing unconventional resources? Are policies evolving that reflect the specific features of unconventional resources?

In section 2 Russia's overall conventional oil reserve situation is assessed and in section 3 the Russian definition of unconventional oil and the most promising production regions are presented. Section 4 discusses the challenges in accessing unconventional oil, comparing Russian conditions with the experience from the USA. Section 5 highlights Russian efforts to overcome some of the institutional problems and reviews recent policy proposals, before conclusions are drawn in section 6.

2. Russia's conventional resource base – still a potential?

The reserve classification system in use in Russia operates with the categories A, B, C1 for explored reserves. Category A represents reserves already under production, B reserves are proven and developed, but not in production, whereas C1 are discovered and delineated but not yet developed. Altogether these three categories are often translated into "proven reserves," the term used in most Western countries. Categories C2, C3, D1 and D2 represent unproven resources. Category C2 refers to resources in the immediate vicinity of producing fields, whereas categories C3, D1 and D2 represent resources with high/very high degrees of uncertainty.

According to the Ministry of Natural Resources (MPR), Russia had 18.4 billion tons of explored reserves (Russian category A+B+C1) as of 1 January 2016, but it is uncertain if all this is commercially recoverable (see Fig. 1). The ministry also reports that an assessment conducted in accordance with the principles of the Society of Petroleum Engineers (SPE), and which includes economic parameters, arrived at only 11 bill. tons (MPR, 2016).



Source: MPR (2014, 2016)

Figure 1. Russian oil resource base, 2014-2016 (mill. tons)

A striking feature of Russia's reserve base is that almost all of it has been licensed to companies: some 95.7% of the explored reserves and 88.8% of the preliminarily estimated reserves (MPR, 2015a). This situation, a major weakness of Russian resource management policy, represents the continuation of decisions made at the end of the Soviet period, when huge swaths of oil territory which had been controlled by Soviet oil industry organizations were transformed to licenses and granted to oil companies based on the former state production associations (Kryukov and Moe, 1994). With very few new fields now available for licensing, the authorities have limited room for manoeuvre if they want to encourage companies to start or increase production. According to the All-Russian Petroleum Scientific-Research Geological Exploration Institute (VNIGNI), less than 1 billion tons of poorly explored oil reserves remain unlicensed (Mescherin, 2013). The volume of prognosticated resources is very high, however – almost 70 billion in the D1+D2 categories, according to one authoritative source (Varlamov, 2016).

Increasing recovery rates could offer a potentially important source of oil-production growth. According to the Ministry of Energy, improving the average recovery rate from 37% to 42% would correspond to an additional 4 bill. tons of oil reserves. However, rates have been falling since 1995, stabilizing only in recent years. In new fields, the expected rate is often set at 32% – the same as in 1948.

According to Rosnedra, the federal subsoil resources management agency under the Ministry of Natural Resources, another unused potential lies in developing already explored but not producing fields. Holding some 3 bill. tons of reserves, these could yield up to 50 mill. tons annually. An additional 40 million tons could come from non-producing layers in fields already in production (Mescherin, 2013).

According to the Minister of Natural Resources, a major problem is the depletion of the 'exploration reserve' – areas with the potential for new discoveries. For many years now, additions to reserves have exceeded production, but about 80% of additions come not from new discoveries but from new exploration of fields already in production, where production equipment and infrastructure are already in place (Donskoy, 2014; Kryukov and Moe, 2007). (See Table 2.)

Table 2. Production and addition to reserves, oil and condensate (mill. tons)
- About here -

In Russian energy-strategy documents, as well as in statements from officials in the Ministry of Energy, the emphasis has been on exploration and development of new traditional reserves in increasingly remote locations. This is reflected in the latest official version of the Russian Energy Strategy, the key overall strategy document for the energy sector (Energy Strategy, 2009). The first draft version (March 2014) of the new Russian Energy Strategy until 2035, also prioritizes developing new petroleum complexes in eastern Russia, and developing the hydrocarbon potential of the Arctic continental shelf.

However, the document also states: 'Strategic goals for development of the oil complex include … intensified development of new approaches and the studying, exploration and development of steadily more complex forms and sources of hydrocarbons, including non-traditional' (Energy Strategy, 2014). In a new draft version from February 2017 the commitment to develop unconventionals was made more concrete: the share of hard-to-recover resources in total oil production should increase from 8 to 17% (Energy Strategy, 2017). However, finalization of the new energy strategy has been seriously delayed. Normally it should have been adopted in 2014, but by end of 2017 it was still not submitted to the government, due to internal disagreement on several issues.

Attention to unconventionals has risen recently, but it is not given that actual policies will be in line with overarching priorities. All alternative policies and developments entail uncertainties related to costs and technology, and they differ in corporate backing and support from various factions in the government bureaucracy, as well as from regions. Unconventionals must compete for attention as well as funding with other alternatives.

3. Unconventional oil in Russia

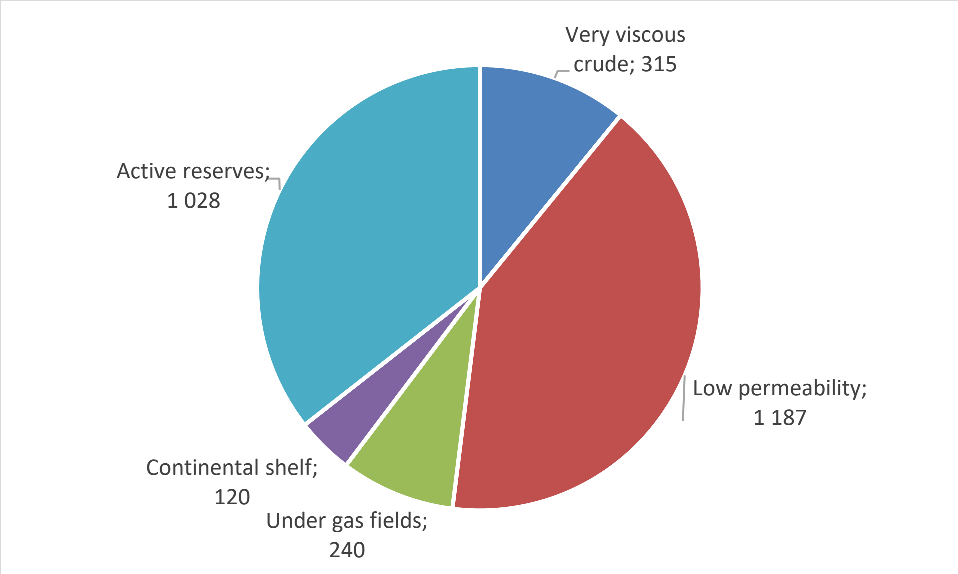
The broadest definition of 'unconventional' oil resources is simply all resources that cannot be extracted using traditional methods. But what is 'traditional' may change over time, and technology developments can shift a source from unconventional to conventional. Historically, and internationally, deep-water oil was long categorized as unconventional – but not today.

'Hard-to-recover-reserves'– Trudnoizvlekaemye zapasy, usually referred to by its acronym TRIZ – is the term usually applied in Russia, dating back to before the unconventional revolution. Main sub-categories of TRIZ reserves are

- shale resources
- low-permeability or -porosity reservoirs – also referred to as 'tight oil'
- bitumen

In general, such 'definitions' use several parameters, geological characteristics and technological requirements. However, costs are rarely included (Yaschenko et al., 2015).

More than 60% of Russia's undeveloped reserves are in the C2 category (Shpurov, 2017) – preliminary estimated or inferred reserves, i.e. insufficiently explored (Kryukov and Moe, 2013a). Much of these undeveloped oil reserves belong to the TRIZ category. Thus, the unconventional *resource* potential in Russia is huge, but the volume of *proven reserves* – explored, evaluated and prepared for exploitation – is much smaller. The State Commission on Mineral Reserves estimates that there exist some 800 mill. tons of 'commercial' unconventional reserves (Shpurov, 2017). According to Rosgeologia – the state geological holding – Russia had 28.9 bill tons of recoverable oil reserves as of 2012, of which 65 per cent was made up of TRIZ, see Figure 2. But the inclusion of C2 reserves in the total makes 'recoverable' a very uncertain proposition.



Source: Panov (2014).

Figure 2. Currently recoverable oil reserves (categories ABC1+C2) 1 Jan. 2012 according to Rosgeologia (mill. tons)

In the USA, the term 'unconventional oil' is commonly reserved for shale-oil and tight-oil resources. Briefly put: 'Shale oil is a high-quality crude oil that is embedded between layers of shale rock, impermeable mudstone, or siltstone. The rock must be fractured to release the trapped layers of oil' (Amadeo, 2016). 'Production of tight oil comes from very low permeability rock that must be stimulated using hydraulic fracturing to create sufficient permeability' (Schlumberger, nd). Thus, shale-oil is really a sub-category of tight oil.

All these resources require the use of horizontal drilling and hydraulic fracking, two key technologies. In this article, we focus on these categories of unconventional oil, but reference will also be made to other hard-to-recover resources or projects, since they involve some of the same institutional challenges.

Shale- and tight-oil resources and their exploitation have characteristics that either differ from traditional oil development or are more dominant than with conventional oil. One distinguishing feature of these resources is their heterogeneousness. Not only do the geological conditions vary, there are also major differences in assessments of appropriate technical solutions and costs, making it almost impossible to apply traditional Russian normative procedures for geological and economic assessments. Nevertheless, attempts are made to assess the potential. According to VNIGNI, Russian shale-oil resources could yield some 50 mill. tons annually, if exploited intensively (Varlamov, 2016).

Potential unconventional resources are not spread evenly around the country, however. Tatarstan and West Siberia (Khanty-Mansiysk and Tomsk) are of particular interest

3.1 Tatarstan

The Republic of Tatarstan has a long oil history. It was the leading Soviet oil-producing region in the early 1970s, with production peaking at 103.7 million tons in 1975 (Dienes and Shabad, 1979). Figures then fell rapidly, until stabilizing at around 25 mill. tons in the mid-1990s. Production has since increased somewhat, reaching 35.5 mill tons in 2016 (Biznes Online, 2017a), 28.6 mill tons of which were produced by the oil company Tatneft, controlled by the republic. (Sychev, 2017).

As of 1 January 2015, Tatarstan had 928.3 mill. tons of proven reserves (A-B+C1) plus 175.2 mill. tons in the C2 category. The resource base is becoming increasingly complicated, however, and hard-to-recover reserves constitute 78.4% of the total (Strategy, 2015). The republic aims to stabilize and slightly increase oil output up to 2030 through various measures, including increased exploration drilling and horizontal drilling, and enhanced recovery.

Exploitation of unconventional resources is also a priority. The most promising unconventional resource in Tatarstan is natural bitumen. Estimates vary widely, but between 7 and 8.7 bill. tons are considered realistic. Of this, 1.5 to 2 billion tons are given priority for development. Actually, this is not a new discovery: two fields have been used as experimental ranges since 1978 (Malikov, 2015).

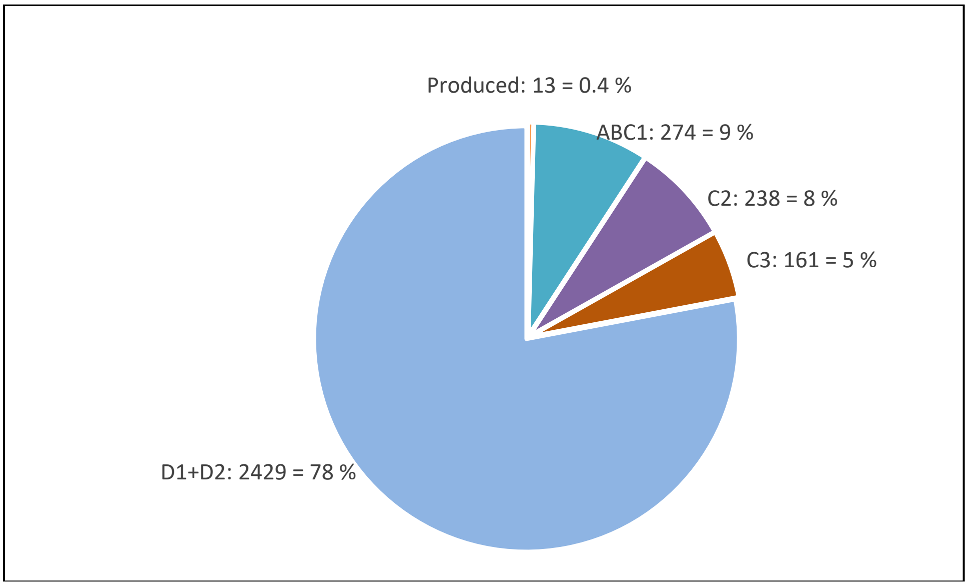
Tatarstan also has a potential for tight-oil production, primarily from the Domanikov Formation – ‘low-permeable cherty limestone sediments’ (Rosneft, 2017). Interesting prospects have been found around the Romashkino field, the old giant which was the backbone of the republic’s oil industry, and also in other oil fields. Fracking has been conducted in one formation, yielding 8 tons per day. Tatneft has included 26 million tons of shale oil in its reserves (Malikov, 2015).

3.2 West Siberia

Khanty-Mansiysk Autonomous District has dominated Russian oil production since the late 1970s. Although output is gradually declining, production was an impressive 239.2 mill tons in 2016 – almost half of Russia’s total output (RIA Novosti, 2017). The region, which covers some 543 thousand square kilometres, has large undiscovered conventional resources, but attention is increasingly paid to unconventional sources.

The Bazhenov Formation, including the underlying Abalak Formation, covers practically all of West Siberia, including Khanty-Mansiysk, and is world's biggest shale formation, located at depths of 2–3000 meters. Importantly, parts of the formation can be accessed from areas which already have a developed production infrastructure, directly on the territory of conventional oil fields under production. Assessments of the resource base differ widely, the range from 600 mill. tons to 174 billion tons of light oil (Rogtec, 2013). According to the draft Russian Energy Strategy until 2035, production from the Bazhenov Formation could reach 20 mill. tons by 2030 (Energy Strategy, 2017).

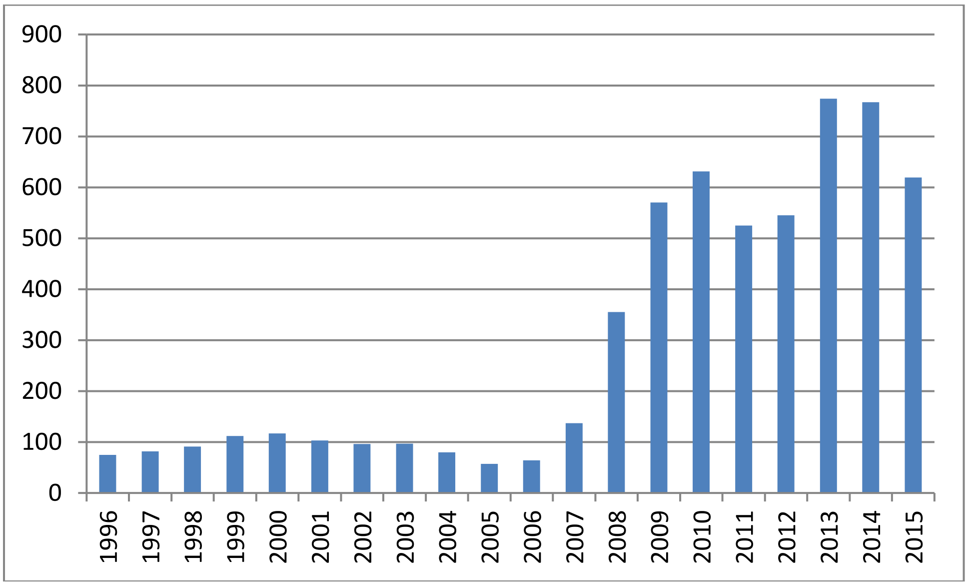
The differing resource estimates are explained by the low level of investigation of the Bazhenov Formation, as well as lack of technology for exploitation. We believe that Figure 3 reflects more realistic assessments based on actual geological fieldwork. Only 273.5 mill. tons are categorized as reserves (ABC1), whereas the bulk consists of prognosticated resources (D1+D2) amounting to 2427.8 mill tons.



Source: Stulov, 2015. For explanation of categories see Figure 1.

Figure 3. Initial oil resources in Bazheno-Abalak Formation by resource category (mill. tons and percent of total)

Even with these lower estimates, the Bazhenov Formation is clearly of considerable interest. As of early 2016, four vertically integrated companies (Rosneft, Surgutneftegaz, Gazprom Neft, Lukoil) plus 14 independent companies were producing oil in the Bazheno-Abalak Formation. However, the volumes of unconventional oil extracted were miniscule– only 774 thousand tons in 2013, the year with highest output (see Fig. 4).



Source: Morozov, 2017.

Figure 4. Oil production, Bazheno-Abalak Formation (thousand tons)

Figure 4 indicates that sustainable successful approaches to development of resources in this area have not yet been found. But there are exceptions: the company RussNeft managed to achieve a stable output of 100 tons per day from a well in the Bazhenov Formation (Russneft', 2017).

In Tomsk oblast (province), 46% of industrial-category oil reserves have been produced. However, it is expected that 123 mill. tons of unconventional oil are exploitable, with similar volumes in the less-certain C2 category. The oblast covers part of the Bazhenov-Abalak Formation; resource assessments will probably rise with further geological work (Kasparov, 2014).

4. The challenge of shale oil

In the research literature on unconventional oil and gas there is a vast body of work on the technological aspects. These industries have, however, also attracted considerable attention in the social sciences. The major reason for this is the social impact of projects that often are located near populated areas. Fear of groundwater pollution and induced seismicity, in addition to traditional environmental and social impacts of industrial activity, make the relationship to society and public acceptance crucial components in successful exploitation of unconventional resources (EPA, 2015; Clark et al., 2015; Davies et al., 2013).

In the case of Russia the social dimension of unconventionals may eventually also become important, but we will argue that at this stage it is not central, for three reasons: 1) The industrial activity taking place today is limited and mostly confined to areas away from population centres, 2) Conflicts with private property owners are unlikely, because of more or less absence of private land ownership in relevant areas, and 3) Popular involvement or protest play a much smaller role in economic and industrial developments than in many other countries, although it has not been inconsequential in certain cases related to social grievances (Ferris-Rotman, 2017).

Thus, rather than applying a holistic framework for analysis of development of unconventionals, as proposed by e.g. Lozano Maya (2016) and Gamper-Rabindran (2018), we want to focus on the more immediate industrial preconditions for development of unconventional oil and discuss how they relate to the Russian institutional environment: Organization of the oil industry, availability of infrastructure, taxation, existence of and access to geological data, conditions for technological development and technology diffusion.

4.1 Diversity in resource base – diversity in industry

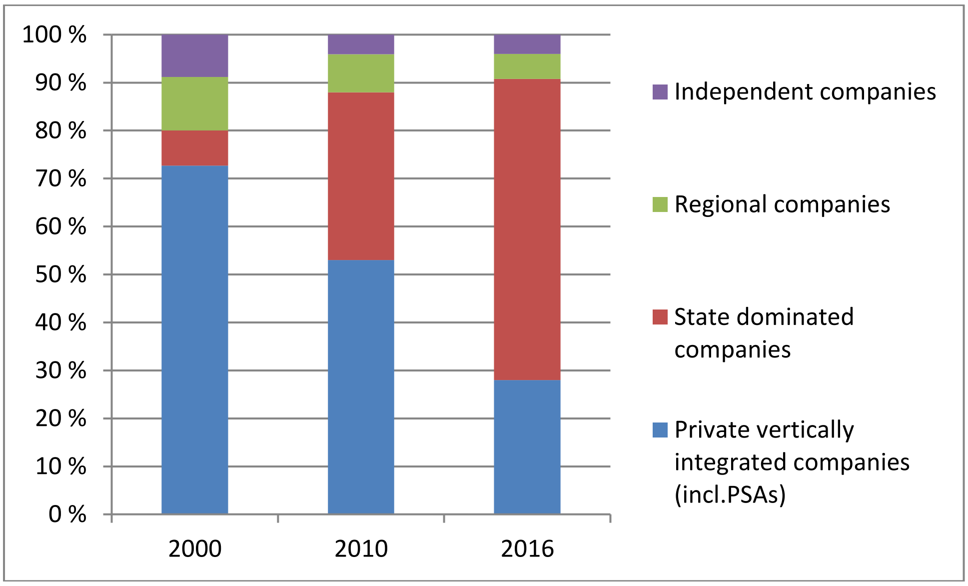
In conventional oil production, a field is developed as an integrated project with several wells. By contrast, in the shale industry, each well is a separate operation, independent of how other wells in the same area are being worked. Within one formation there may be sizeable differences in geological characteristics, making flexibility and rapid adaptation essential. Companies in the same area may apply different strategies and technologies. 'Shale companies need to move on a micro-scale, on multiple micro-objectives by flexibly leveraging on time and opportunities and know almost perfectly the environment they are operating in' (Maugeri, 2013). Results from one well are used to fine-tune further drilling. The shale-oil business is still an evolving industry without established best practices.

With a conventional oil field, production builds up over several years, and then stays at plateau level for a long time. In the shale-oil industry, however, new wells must be drilled continually, to sustain production. Whereas conventional fields require long-term investments based on expectations of future prices, production from shale formations can be adjusted quickly in line with current oil prices, by increasing or curtailing drilling. Shale-oil production is more flexible and yields revenues faster than does opening new, conventional oil fields – but it requires rapid and flexible decision-making.

Exploitation of shale oil calls for a business model different from conventional oil production. Smaller companies or units with considerable autonomy within larger companies will be better suited to tackle such challenges – and they tend to be more innovative. But they must also have the financial muscle to survive periods of low prices and limited drilling.

In countries with a mature petroleum sector, a diversified industry structure is usually regarded as a precondition for effective resource management. Small, specialized companies take care of tail production from fields no longer of interest to bigger companies, and specialized exploration companies venture into new areas with particular challenges, turning any discoveries over to regular production companies. The role of small, independent companies is also recognized in Russia – in principle. In the words of the Minister of Natural Resources: 'It is not a secret to anybody that precisely small, innovative collectives start the breakthroughs in directions previously not regarded as interesting by the big companies' (*Komsomolskaya Pravda*, 2015).

With the resource base becoming more diversified and complicated, a corresponding change in the structure of the oil industry might be expected. In Russia, however, developments are going in the opposite direction. The organizational structure of the oil industry is dominated by large companies, also regarding the development of small unconventional projects.



Source: Assoneft', 2016.

Figure 5. Russian oil industry: Company categories (% of total oil production)

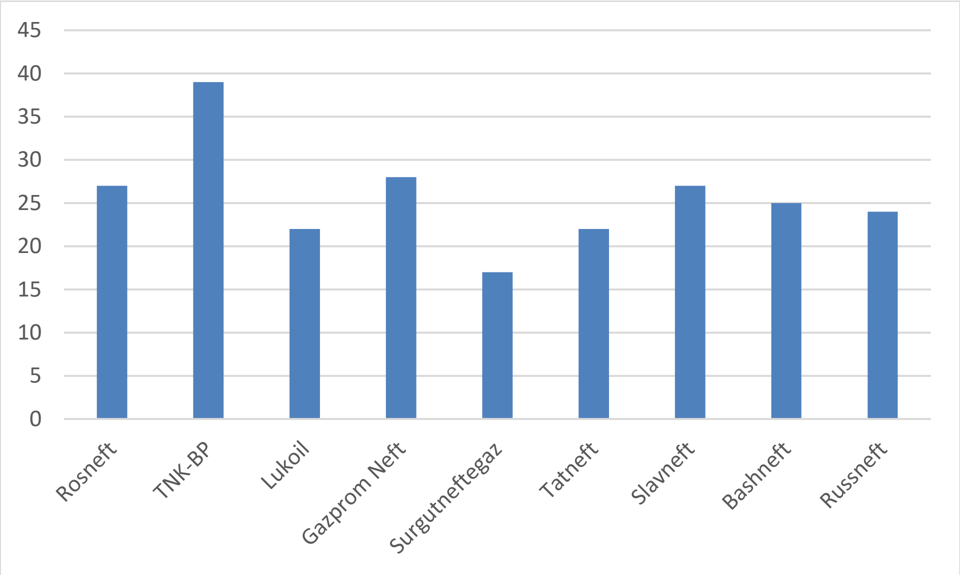
As shown in Figure 5, there is increasing concentration in the Russian petroleum industry; the number of independent actors is very small. Particularly striking is Rosneft's transformation from a medium-sized company with unclear state-related tasks to becoming the country's leading oil company. As of 2015, it directly accounted for 35% of Russia's output, in addition to its stakes in several other companies and joint ventures.

Only some 150 small and medium-sized producers, accounting for approx. 4% of Russia's total production, are truly independent (Andrianov, 2017). By comparison, in the USA in

2014 there were 7,000 independent companies, responsible for 46% of production and 94% of exploration and production drilling (Anokhin, 2015).

Within Russia there are major regional differences. In Tatarstan there are 32 small companies, producing some 21% of the republic's oil. However, several of these can hardly be called independent, as their owners have ties to major companies (Biznes Online, 2017b).

The big Russian companies all have huge resource bases, with reserve-to-production rates of 17 to 39 years (2013), as shown in Figure 6. This means that they are in no desperate hurry to enter unconventional projects.



Source: Numbers derived from MPR (2014).

Figure 6. Reserves-to-production rates, major Russian oil companies 2013 (years)

A large and centralized vertically integrated company will compare investments in the still-uncertain unconventional sector– perhaps including technology development – against investments in already operating oil fields. The latter will probably be preferred, because the return on investments will be much higher there. It is notoriously difficult to operate with highly differing economic criteria for projects within one company. A company with a long-term view might see that investments in start-up of unconventional projects now could bring more profits over time, but the uncertainty is high. The question of long-term vs short-term gains, a perennial issue in discussions about the Russian economy, is relevant also here (Kryukov and Moe, 2013b)

There will also be differences in the optimization of investments as seen from the corporate headquarters of a large vertically integrated company in Moscow, compared to a regionally based company or regional authorities. A regionally based company will have fewer options and be inclined to make the most of these in its territory of operation. Such companies may also possess local knowledge – valuable in the selection of plots, for example. A case in point is Irkutskaya Neftyanaya Kompaniya, which has developed complicated deposits in Irkutskaya oblast' (Irkutsk, 2017). Regional authorities are likely to emphasize the social aspects of unconventional production: regions struggling with unemployment will appreciate the considerable need for manpower. Social acceptance and environmental concerns do not seem to be restraining factors, unlike in many other potential shale-oil or -gas producing countries.

In the USA there have been many independents willing to take high risks. However, they do not act in isolation. The diversified oil industry structure there is supported by access to venture capital and an environment favourable to risk-willing investors, so an investor will be richly rewarded if the investment project is successful. The situation in Russia is totally different; moreover, there are few banks and credit institutions willing to hedge price risks.

Only big companies are likely to have the financial muscle necessary to invest in technology development: they can cover losses with revenues from profitable conventional projects.

Thus paradoxically, only the big companies, with little interest or incentive to engage in unconventional resources, are those able to do so on a larger scale – as some big companies have done. For example, Surgutneftegaz has been conducting extensive experimental projects, including technology development, in the Bazhenov Formation since 2006. However, over the first six years they managed to produce only some 1.5 mill. tons: the economic loss was about 4 bill. rubles, equivalent to approx. USD 110 mill. at the time *(Neftegazovaya Vertikal'*, 2012.

The industry structure and lack of risk capital represent serious challenges for developing Russia's unconventional resources. However, we must also ask whether policies can compensate – a point to which we return in section 5.

4.2 Importance of existing infrastructure and availability of rigs

The availability of roads, pipelines, electric power and water supply is important, as it seriously affects start-up costs. For relatively small or economically marginal projects, the prior existence of relevant infrastructure may be decisive, unlike the case with a large conventional greenfield project capable of bearing the costs of infrastructure. Shale-oil production generally has narrower margins than conventional oil; and whereas the profitability of a conventional oil field is determined largely by the resource base, the economics of unconventional oil is highly dependent on available infrastructure, pipelines and water supply:

> In the shale arena, once you know that reserves are present, success is more about spending money wisely across many wells. And, given shale's lower margins, every penny counts – so being able to use existing infrastructure, for example, can make the difference between making or losing money on a well. (Boston Consulting, 2013)

From the outset, Russia is at a disadvantage compared to the USA. In most areas in the USA where shale-oil activities are underway, previous oil exploration has been intense. This provides a developed infrastructure, as well as an extensive geological data base (see section 4.4). As noted, promising unconventional resources in Russia are found in old oil-producing regions like Tatarstan and Khanty-Mansiysk. But these regions are immense, drilling density has not been high, and new infrastructure is needed in many cases.

Production from a shale-oil well reaches maximum quickly, within weeks. To maintain production, new wells must constantly be drilled. This in turn requires the availability of a large number of drilling rigs. In the USA in 2014 there was an average of 1527 rotary rigs drilling for onshore oil in operation, sinking to an average of 408 in 2016 (EIA, 2017). These figures reflect not only reduced drilling activity, but also higher utilization rates for each rig, as well as indicating the high availability of rigs. In Russia there were reportedly 1500 functioning rigs as of 2014, most of them more than 25 years old (Neftegaz.ru, 2014). Improving this situation will take time and require investments – directly by the oil companies, or by drilling companies renting out equipment or providing drilling services.

4.3 Taxation

Oil and gas taxation in Western countries is normally based on net income: costs are deducted before tax is levied. The specific rules for cost deductions vary, but a net-based tax system will usually reduce the risk of starting a new activity, provided the investor has an income from which costs can be deducted. This again depends on whether projects are 'ring-fenced', i.e. projects or fields are taxed separately. If they are, costs can be deducted only from income from the given project. In the USA there is no ring-fencing, so a company can deduct the costs of a new tight-oil project from income elsewhere. This principle offers encouragement tor companies starting unconventional projects, but it is fully relevant only for federal income tax. American states have additional taxes, sometimes levied on gross income; even counties and municipalities may levy additional taxes and fees, with conditions varying from location to location. Companies must also pay a royalty to the private land owner. Nevertheless, in general the American taxation system encourages investment. There are also special schemes for tax credits on research and development, on the federal and state level, as well as tax incentives for production in marginal projects (Deloitte, 2013).

The taxation system in the Russian oil sector is very different. It is based on gross income, which means that from the outset total revenues are taxed at a given rate, without expenditures or investments being deducted. The aim is fiscal: to secure tax income. Such a system is simple to administer, and it offers predictability. The major argument against net-based taxation in Russia is that costs can easily be manipulated in an incompletely developed market economy. This is the main reason why it has been difficult to achieve a reform involving the transfer to taxation of the net financial result.

However, a taxation system based on gross income leads companies to avoid high-cost or high-risk projects, as these will be taxed at the same average rate as less complicated ones. To counter this tendency, Russian authorities have implemented a series of tax concessions for specified remote regions and complicated production conditions. Modifications in the tax on mineral resources (NDPI) can be understood as an attempt to take into consideration economic conditions in various parts of the resource base. The tax rate can be differentiated according to the collector's permeability, i.e. the rock's ability to transmit fluids, the level of exhaustion of the field and the size of the oil-bearing layers. But tax breaks for 'hard-to-recover' projects are available only to new projects for developing oil from a specific deposit. The resultant system is highly complex, and it is difficult for an investor to predict the tax rate for a given project (Fjaertoft and Lunden, 2015).

Moreover, one may question the effects of tax breaks intended as incentives to companies to engage in complicated exploration and field development projects, including unconventional resources. Assessments of the effect of tax breaks accorded to big companies for unconventional development indicate that these breaks have served merely to make marginal projects profitable: they have not led to investment in new technologies (Neftegazovaya Vertikal', 2016). Tax breaks alone appear to have limited significance: they need to be implemented in a setting where actors are open to such signals – but the big companies lack any fundamental interest in unconventionals.

4.4 Earlier geological knowledge

Experience gained from previous conventional oil activity can contribute greatly to reducing the risks of starting shale-oil drilling. The availability of, and access to, drilling cores as well as data are important cost-reducing factors. In the USA – as in many other oil-producing countries – information from petroleum exploration is meticulously recorded, as processed data and in the form of core samples. The Bureau of Economic Geology's Houston Research Center has a collection of some 900,000 boxes of core samples from all over the USA (Bureau of Economic Geology, nd), catalogued and searchable. Users can 'search by state, county, API number for the well, they can search operator, lease name' (Gronewold, 2013). There are also other large collections in Texas, as well as in other states (Troutman, 2009). The Railroad Commission of Texas, which regulates the petroleum industry in the state, holds 'an estimated 132 million pages of analogue and digital documents encompassing the history of each Texas oil and natural gas well from the drilling permit application to the final plugging' and also other data related to oil and gas activity in Texas (Railroad Commission, 2017). Everything is searchable.

Such data are crucial assets for the American oil industry, including shale oil. They make it possible to select promising sites and develop exploration plans according to the specific features of the site, at very low cost. This means that the investment risk is radically reduced compared to a situation where a company needs to explore large undeveloped areas first.

According to the fundamental Russian law 'On Underground Resources', 'information about the geological structure of the underground, the presence of exploitable resources, about conditions for their exploitation … may be state property or the property of resource users', depending on how exploration has been financed (Law, 1992: para 27). Geological information includes 'primary information' acquired during resource use (exploration or production) like core samples and data from geophysical and geological work, as well as 'interpretation' after processing of primary data. The resource user has exclusive rights for three years to primary information and five years to interpretations; thereafter, there is to be open access to the information (MPR, 2015b). Further, geological information about the subsurface must be transferred to the federal geological collection (Rosgeolfond) and corresponding territorial collections of geological information – but no procedures for doing this exist, and the transfer of data has been very incomplete.

A serious problem concerns not the 'new' data collected after the Law on Underground Resources was adopted in 1992, but the earlier 'historical' data accumulated by various state organizations. In Soviet times, exploration and processing of core samples was conducted by organizations under several different ministries. Paradoxically, data management in the centrally planned economy was decentralized. Storage of primary information, mainly core samples, was the responsibility of the field organizations that had collected it, usually on the territory where it came from – spread out around the entire USSR. In practice, almost only secondary information – data analysis – was stored at the regional level, at the regional headquarters of geological organizations or oil and gas production associations.

With the reorganization of the economy after the end of the Soviet Union, new commercial structures emerged based on former state organizations. In this process, marked as it was by uncertainty and economic difficulties, concern for old data collections, understandably, did not enjoy high priority.

This attitude to data and information storage also had a deeper explanation. In the centrally planned economy, the main purpose of information was to solve immediate tasks – identifying new hydrocarbon deposits that could be developed industrially. Top priority was given to the volume of exploration drilling and to increasing reserves from conventional sources. Processing of older data is important for developing unconventional resources – but this was not prioritized.

The extensive approach to resource development, focusing on big new fields – rather than an intensive approach of increasing the recovery from each deposit – was characteristic of the USSR, and has remained prevalent in Russia (Kryukov and Moe, 2013a). Even today, the success of geological companies and organizations is usually seen as a function of reserve additions, meters drilled, and seismic surveys carried out. Value vs costs is not a major issue.

Nevertheless, understanding of the importance of geological information has improved. In the 1990s there were several attempts to store old information in regional centres, particularly in Khanty-Mansiysk, Yamal-Nenets, Tomsk and Tatarstan. Since then, the role of the regional level in the Russian Federation has diminished, but the big oil companies have introduced corporate data storage systems and intensified the development of electronic databases. After 2010 there have been efforts to establish a complete, centralized catalogue under the auspices of the Russian Federal Geological Fund (Rosgeolfond) of all the data collections from various territories and organizations, and to establish a unified depository for geological information (MPR, 2015b). In January 2016 changes in the Law on Underground Resources entered into force, clarifying rights and responsibilities as to the storage and use of geological information, and mandating the transfer of primary as well as secondary geological information to federal organs (Law, 1992).

This process is far from concluded. Geological information has not been systematically collected everywhere. And even where there are collections, they are often not accessible to all – due not only to ownership issues and secrecy, but also for purely technical reasons, like lack of storage capacity/ information management systems. In many cases, core samples have been thrown away or lost. This is a serious disadvantage to those potentially interested in the exploitation of unconventional resources. Lack of accessible and representative information constrains modern data processing and work on unconventional hydrocarbon resources. Without historical data, new primary data must be collected, entailing further costs.

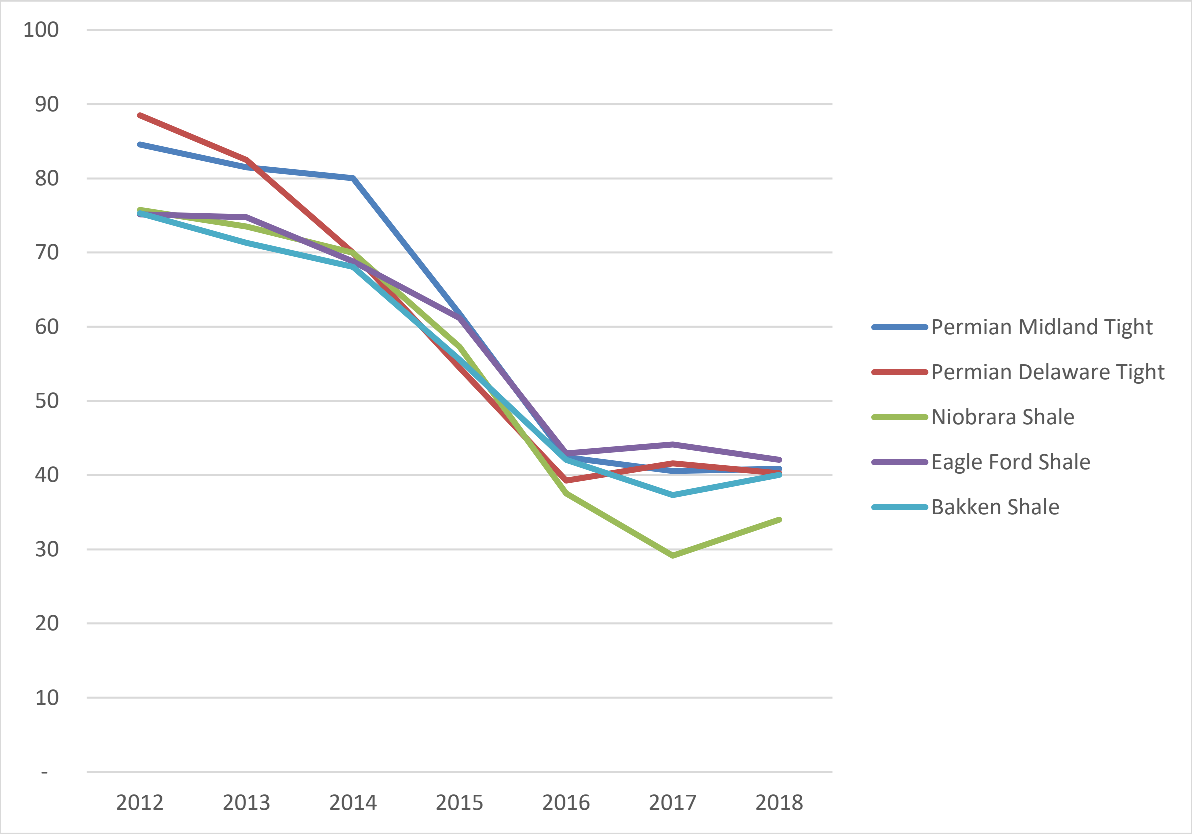
4.5 Learning and technology development

The immediate explanation for the rise of unconventional production in the USA is the application of two key methods and technologies – horizontal drilling, and hydraulic fracturing ('fracking') (Howarth et al. 2011). The technologies had been known separately for a long time, combining them was the key to shale resources. But for several years costs were regarded as too high for most shale projects to make commercial sense. The breakthrough for shale-oil came when the oil price had reached a relatively high level. But even in that period the need for cost-cutting was apparent, and it became stronger with lower oil prices.

> Unconventional resource plays *[formations]* sit firmly at the expensive end of the marginal cost curve for oil supply. Subsurface conditions are more rigorous; specialized technology and manpower are costly. To guarantee success, and to be able to operate through price cycles, operators must continually strive to reduce cost on a unit (barrel) basis. They can do this by scaling up production volumes, so long as

business conditions and other constraints (like policy and regulation) permit. Technology adaptations can help to eventually improve recovery rates, a target for sustainability and future pathways in unconventional plays, thus lowering costs and supporting profitability (Foss, 2012: 53).

A system which can disseminate knowledge about technologies widely is a prerequisite for rapid cost improvements. The American experience has shown a remarkable ability to reduce costs in a relatively short period. Statements heard not long ago about an oil price of USD 70 or 80 as the minimum required to sustain shale-oil production, have proven completely wrong. As shown in Figure 7, the break-even price for major shale formations was reduced from the range of USD 66–98 in 2013 to USD 29–39 in 2016.



Source: Rystad Energy NASWellCube.

Figure 7. Development in wellhead break-even oil prices for key USA shale formations (USD/bbl).

Generally, the shale-oil business is characterized by high risk levels. Mitigating such risks requires constant revision of approaches and adaptation of technologies.

Access to and application of the basic technologies – horizontal drilling and fracking – cannot be considered an obstacle to the development of unconventional oil and gas in Russia, where both technologies have been in use for many years. Hydraulic fracking entered with the joint ventures established in the early 1990s, but the basic technique had been developed in the Soviet Union in the 1950s – although it was not applied. Horizontal drilling was introduced in Russia by the international oil services company Schlumberger in 2000 (Gustafson, 2012). But unconventional resources in Russia have characteristics and locations which often make it impossible to apply technology and approaches developed in the USA directly. The head of the Russian State Committee for Reserves has even stated: 'it is necessary to develop a new scientific discipline – petroleum geology and hydrodynamics for superlowpermeable rock' (Andrianov, 2016a). We must then ask: how are the institutional conditions for development and dispersion of new technologies?

The development of technologies (and access to them) assumes differing forms in different countries, historical periods and under different organizational conditions. In developed market economies, the state supports basic research for the development of new technologies. Individual companies develop proprietary technologies on their own risk. At the same time there are mechanisms for dispersion of new knowledge. The mobility of experts and the existence of professional networks and societies play a role here.

By contrast, in a centrally planned economy – and the Russian economy is still characterized by hierarchical management – the state is pivotal, not only in supporting fundamental research, but also in technology development as well as training of specialists. Moreover, special state companies or institutions are established to create and distribute new technologies. This system is not only rigid – it trails behind in developing new technologies, and it operates with high costs and complicated mechanisms for decision-making around innovations (Vercueil, 2014).

This 'industrial paradigm' for development and diffusion of knowledge was traditionally based on a linear model of the innovation process, with separate stages for fundamental and applied research and the implementation of new equipment and technological processes. Historically, this model may have been appropriate, but is becoming less and less relevant. Today, individuals with unique experience and knowledge are the prime agents of change. Increasingly, the linear model is being replaced by a more complex network model involving constant interaction and feedback across what were previously regarded as separate stages. Sometimes the development process is aborted and reverts to the initial stage; or it may be accelerated and omit a stage altogether, e.g. implementing nascent technologies on an experimental basis. This is especially relevant in the case of accessing unconventional petroleum resources.

In Russia the system for studies, mapping, and exploration of mineral resources as well as development and diffusion of new technologies has been linear and hierarchical, with emphasis on conducting the stages in the correct order. The strength of this system lay in its ability to map, explore and bring into production new mineral deposits, in virgin territories as well as in already producing regions. However, there is now less and less potential for developing relatively big or geologically uncomplicated, previously discovered oil fields in Russia. The resource potential is huge, as outlined in section 1, but its composition is complicated and diverse. This makes it crucial to have expert knowledge about the specific geological conditions in objects for possible development, as well as appropriate technologies. Can we see any change in the policies being developed today?

A 'Plan of Action for Development of Unconventional Hydrocarbon Sources' presented in the Ministry of Natural Resources in 2014 (Nikitin, 2014) set out principles for the approach to unconventional hydrocarbons. This important document formed the basis for amendments to the Law on Underground Resources, presented in June 2017 (Law, 1992).

The Plan of Action calls for

- First, scientific research aimed at establishing a 'technical-methodological prognosis' for exploration and development of accumulations of unconventional resources.
- The next step is establishment of test-ranges – *poligony* – for development of technology
- Quantitative assessments of unconventionals are to be conducted throughout the country, prior to geological-economic assessments comparing the capital costs involved in various accumulations.
- On this basis, a programme for development is to be agreed on with potential resource users (companies).
- The legal framework for resource use adapted to development of unconventionals shall be elaborated, as well as a methodology for economic stimulus of mapping, exploration and development.
- Finally, organizational measures are to be established for the licensing and use of unconventionals.

The Plan of Action follows Russia's time-honoured linear/ hierarchical system for accessing resources. It does not improve the conditions for broader usage and dispersion of new technologies and adaptation of general technological approaches to the specifics of individual objects. Broader usage would mean more effective application, and thereby cost reduction. But it requires mechanisms for the transfer of technologies and experience from company to company, learning from experience with the dispersion of new technologies. Russia has endeavoured to address such issues through other mechanisms.

5. Experimental ranges: A solution to institutional problems?

The presence of unconventional liquid hydrocarbons, including heavy oil and high-viscosity oil, has long been recognized in Russia. Attempts were made already in Soviet times to develop such resources. The idea was to develop universal technologies to evaluate and develop the resources and find ways to systematize and simplify development and dispersion of new technologies. In 1986, the scientific-industrial complex *Nefteotdacha* ('oil recovery') was established specifically for this purpose – based on central planning and central management. However, this state organization was shown little interest by the oil industry; and the oil companies that emerged after 1991 generally did not want to experiment with new technologies, preferring internationally proven methods. Nefteotdacha was reduced to a small service company within the structure of the state oil company Zarubezhneft; by 2015 it had a turnover of only approximately 15 mill. USD (Nefteotdacha, nd).

Another attempt involved creating special innovating oil companies – like RITEK (Russian Innovative Fuel and Energy Company), established as a daughter company of Lukoil. According to its founders, the company was developed from the 'idea of a new concept for managing the innovation activity based on a structured and regulated information system…' (Grayfer et al., 2002). RITEK has now become totally dependent on Lukoil and only conducts R&D for that company.

The most recent attempt to overcome the problems of developing the right technologies for exploitation of a changing resource base, while also creating the preconditions for dispersion of new technologies and methods, has been the establishment of a series of *poligony*, experimental ranges. The idea is to establish experimental ranges for technologies for recovery of various forms of hard-to-recover oil in several parts of the country (Prusakov, 2017). *Poligony* development has now become urgent, because of the high reliance on imported technology. According to the Analytical Centre of the Russian Government, in 2016 between 40% and 60% of all technology for development of hard-to-recover-reserves was imported (Andrianov, 2016b). Moreover, sanctions imposed on Russia from 2014 included transfer of technology to shale-oil projects (Department of the Treasury (US), n.d.).

Tatarstan, in cooperation with the Federal Ministry of Natural Resources, established two scientific experimental ranges in 2015 for the development of technologies for exploiting bitumen and shale oil. This initiative is expected to help spread innovations (Malikov, 2015). In the Bazhenov Formation in West Siberia the idea is to develop technology within an experimental range, and on this basis establish a consortium of oil and service companies with a shared goal: to elaborate effective technologies for developing the structures within the range, especially those containing shale oil and shale gas. An area of 150 km^2 has been set aside for the range. According to the work plan until 2020, a detailed geological-geophysical model of sediments in the Bazhenov-Abalak Formation is to be prepared, a series of test wells will be drilled, including horizontal wells with horizontal extension of 1000 m., and core samples will be extracted. Lastly, production clusters are to be established and technologies approved. The main financial source for the programme is the federal budget (Shpil'man, 2015). In Tomsk another experimental range is under establishment. It is research-oriented with the emphasis on geology. The main goal seems to be to identify geological objects with a view to securing special treatment and tax concessions. The work plan follows a strictly linear and hierarchical logic (Kasparaov, 2014).

These *poligony* are based on the idea of creating a universal 'package' of technologies for different types of complex layers of oil. An important goal is to spread results to the whole oil sector in Russia. A draft law presented by the Ministry of Natural Resources in June 2017, aimed at improving the conditions for development of technology, involves establishing a new legal category of resource use: experimental ranges for developing technologies for the exploration and exploitation of unconventional hydrocarbons (Rogtec, 2017). A company would be able to get a license to work in an experimental range for the sole purpose of developing technology, to be financed by regular resource-users – the oil companies. Winners of auctions for such licenses would not have to present detailed plans for resource development, nor pay a signature bonus. What will be decisive is the quality of the technological innovations produced. Yet, no recipe for collaboration between big companies within an experimental range has been found. The draft law, like other policy documents, circumvents a fundamental question: is a prescriptive regulatory regime applicable for developing unconventionals? The traditional Russian approach involves developing standardized, certified technologies that are used in the plans presented by resource-users seeking licenses for exploration or production. But with a heterogeneous, non-standard resource base, regulations will need to be more flexible.

This draft law shows that the central authorities are aware of some of the fundamental obstacles to the exploitation of unconventional resources – but no attention is paid to creating incentives to take the corresponding technological, geological and commercial risks. Indeed, there seems to be no recognition of the role of risk-willing commercial actors.

6. Conclusions

The conditions for developing unconventional hydrocarbons in Russia are inadequate in many respects. Geological data may be lacking, the industry structure is not suited for meeting the specific challenges of unconventional oil, the system for development and dispersion of knowledge is ineffective, infrastructure is often insufficient, and tax incentives do not work. Moreover, access to finance, services and supplies is cumbersome.

Nevertheless, the focus in recent official statements concerning unconventionals has been almost exclusively on the problems of technology and taxes, as in the April 2017 White Paper produced for the Ministry of Natural Resources – 'A concept for development of shale oil in Russia'. It contained resource estimates, comparison of taxation in the USA, Canada and Russia, estimates of break-even price and the consequences of tax breaks for the state budget (Varlamov et al., 2017) – but nothing about special institutional conditions that could favour the development of unconventionals.

The belief that technology can solve the problem remains strong. In August 2017 the Ministry of Energy announced a tender to develop unique domestic technology for extracting oil from the Bazhenov Formation and to prepare proposals for a Bazhenov research programme. This tender focuses exclusively on the centralized development of technology and geological-geophysical studies (Interfax, 2017). And in September 2017, Gazprom Neft declared that Russia was no longer dependent on foreign technology and equipment to produce oil from the Bazhenov Formation (Regnum, 2017).

We hold that technology and taxes are far from the only factors that determine the attractiveness and feasibility of unconventional hydrocarbons in Russia. Not that we question the technical ability of the Russian oil industry to produce oil from unconventional sources – that was proven long ago. The real question is whether sustainable, profitable production of unconventional oil is possible in Russia.

We have indicated institutional conditions likely to limit the potential for exploiting unconventionals in Russia. A fundamental problem is the lack of trust in the expertise of people willing and able to take geological, technological and economic risks. This is reflected in the industry structure, as well as the regulatory framework. The role of the big companies has constantly been strengthened, whereas efforts to develop a modern regulatory environment that can encourage risk-takers and new ideas have been few and weak.

The inadequate institutional environment is a major reason why also many Russian geologists are sceptical about the potential of unconventional oil, despite resource assessments. The head of the West Siberian Scientific Research Institute for Geology and Geophysics summed up this view recently: '...maximum production from licensed fields over the coming 10 to 12 years could reach 3 to 4 million tons annually. The Bazhenov and Abalak Formation is first of all a research object' (Morozov, 2017).

Russia seems set to continue to access its unconventional resource base – with own technology and companies, and with foreign participation. However, given the current institutional environment, achieving large-scale commercial success appears difficult. It remains an open question whether challenges in the resource base will lead to changes in the institutional environment.

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References

All cited web-sites last accessed 28 February 2018.

Amadeo, K. 2016. Shale Oil: The Pros and Cons of Fracking. The balance.com. https://www.thebalance.com/what-is-shale-oil-and-how-is-it-produced-3306195

Andrianov, V., 2016a. Trudnoizvlekaemymi – Ves' mir nauchilsya upravlyat': Rossiya – isklyuchenie. Neftegazovaya Vertikal' (9), 24–30.

Andrianov, V., 2016b. Yesli tekhnoplogicheskikh poligonov ne budet, to kak proverit' kachestvo Importzamescheniya? Neftegazovaya Vertikal' (9), 32.

Andrianov, V., 2017. Obschaya lodka nezavisimykh kompaniy. Neftegazovaya Vertikal' (10), 26.

Anokhin, K., 2015. Tret'ya neftyanaya sila. Kommersant, 16 June. http://www.kommersant.ru/doc/2745702

Assoneft', 2016. Itogi raboty Assotsiatsiya 'AssoNeft' za 2016 g. Presentation by General Director Ye. V. Korzun. 16 December. http://www.assoneft.ru/analytics/dictionary/

Auping, W.L., Pruyt, E., de Jong, S., Kwakkel, H.H., 2016. The geopolitical impact of the shale revolution: Exploring consequences on energy prices and rentier states. Energy Policy 98, 390–399. https://doi.org/10.1016/j.enpol.2016.08.032

Biznes Online, 2017a. V 2016 godu v Tatarstane dobyli 35.5 min t. nefti. 26 January. https://www.business-gazeta.ru/news/335499

Biznes Online, 2017b. Chuzhie zdes' ne nuzhny: komu prinadlezhit Malaya neft' Tatarstana? 12 July. https://www.business-gazeta.ru/article/351239

Boston Consulting Group, 2013. Beating the Best: Eight Characteristics of Winners in the Shale Arena. https://www.bcgperspectives.com/content/articles/energy_environment_cost_efficiency_asset_optimization_beating_best/?chapter=3

BP, 2017. Statistical Review of World Energy. https://www.bp.com

Bureau of Economic Geology, nd. Houston Research Center. http://www.beg.utexas.edu/about/facilities/houston-research-center

Clark, C. E., Hart, P. S., Schuldt, J. P., Evensen, D. T. N., Boudet, H. S., Jacquet, J. B., Stedmang, R. C., 2015. Public opinion on energy development: The interplay of issue framing, top-of-mind associations, and political ideology. Energy Policy, 81, 131-140. https://doi.org/10.1016/j.enpol.2015.02.019

Davies, R., Foulger, G., Bindley, A., Styles, P., 2013. Induced seismicity and hydraulic fracturing for the recovery of hydrocarbons. Marine and Petroleum Geology, 45, 171-185. https://doi.org/10.1016/j.marpetgeo.2013.03.016

Deloitte, 2013. Oil and gas taxation in the United States. Deloitte taxation and investment guides. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Energy-and-Resources/dttl-er-US-oilandgas-guide.pdf

Department of the Treasury (USA), nd. Ukraine/Russia-related sanctions program. https://www.treasury.gov/resource-center/sanctions/Programs/Pages/ukraine.aspx

Dienes, L., Shabad, T., 1979. The Soviet Energy System. V.H. Winston & Sons, Washington DC.
Donskoy, S.E., 2014. O sostoyanii i perspektivakh razvitiya mineral'no-syrevoy bazy RF. Neftegazovaya Vertikal' (14), 16–23.

EIA, 2013. Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States, United States Energy Information Administration. https://www.eia.gov/analysis/studies/worldshalegas/pdf/overview.pdf

EIA, 2017. Crude Oil and Natural Gas Drilling Activity Measurements. United States Energy Information Administration. Monthly Energy Review. October. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

Energy Strategy, 2009. Energeticheskaya strategiya Rossii na period do 2030 goda (Energy strategy of Russia until 2030). Moscow, Ministry of Energy. http://minenergo.gov.ru/node/1026

Energy Strategy, 2014. Energeticheskaya strategiya Rossii na period do 2035 goda –proekt (Energy strategy of Russia until 2035 – draft version). 11 March. Moscow, Ministry of Energy. http://www.energystrategy.ru/ab_ins/source/ES-2035_03_2014.pdf

Energy Strategy, 2017. Energeticheskaya strategiya Rossii na period do 2035 goda –proekt (Energy strategy of Russia until 2035 – draft version) 1 February. Moscow, Ministry of Energy, Moscow. https://minenergo.gov.ru/node/1920

EPA, 2015. Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-16/236F.

Ferris-Rotman, A, 2017. Keep Your Eyes on the Protests in Russia's Provinces. Foreign Policy, April 28. http://foreignpolicy.com/2017/04/28/keep-your-eyes-on-the-protests-in-russias-provinces-putin/

Fjaertoft, D., Lunden, L.P., 2015. Russian petroleum tax policy – Continuous maneuvering in rocky waters. Energy Policy 87, 553–561. http://dx.doi.org/10.1016/j.enpol.2015.09.042

Foss, M.M., 2012. Testimony on 'Tapping America's unconventional oil resources for job creation and affordable domestic energy: technology and policy pathways'. 17 April. Committee on Science, Space, and Technology, House of Representatives, United States Congress. Serial No. 112–75, pp. 42–59.

Gamper-Rabindran, S. (Ed.), 2018. The Shale Dilemma: A Global Perspective on Fracking and Shale Development, University of Pittsburgh Press, Pittsburgh.

Grayfer, V.I., Galustyants, V.A., Vinitsky, M.M., 2002. Metodologiya i praktika upravleniya innovatsionnoy deyatel'nost'yu. Neft i Gaz, Moscow.

Gronewold, N., 2013. Oil and gas core samples could hold clues to greater yields for industry. Energywire. 1 October. https://www.eenews.net/stories/1059988082

Gustafson, T., 2012. Wheel of Fortune. Belknap Press, Cambridge, MA, pp. 191–92, 222–225.

Howarth, R.W., Ingraffea, A., Engelder, T., 2011. Natural gas: Should fracking stop? Nature 477, 271–275.

Hughes, D., 2013. A reality check on the shale revolution, Nature 494, 307–308.

Interfax, 2017. Russia seeking Bazhenov suite technology, aiming for ‘faster, cheaper’ shale revolution than in US. 3 August.

Irkutsk, 2017. About us. http://irkutskoil.com/about/

Kasparov, O. S., 2014. O perspektivakh razvitiya syr’evoy bazy uglevodorodnogo syr’ya i pozitsii Ropsnedr. Rosnedra presentation. 5 March . http://rosgeoportal.ru/association/materials/SitePages/downloads/t%D0%BEmsk05032014_02.pdf

Komsomolskaya Pravda, 2015. S. Donskoy: Nesmotrya na slantsevuyu revolyutsiyu, Rossiya vse ravno mirovoy lider po nefti i gazu. 17 June. http://www.mnr.gov.ru/mnr/minister/statement/detail.php?ID=141430&sphrase_id=629564

Kryukov, V., Moe, A., 1994. Observations on the Reorganization of the Russian Oil Industry, Post-Soviet Geography 35, 89–101.

Kryukov, V., Moe, A., 2007. Russia's Oil Industry: Risk Aversion in a Risk-Prone Environment. Eurasian Geography and Economics 48, 341–357.

Kryukov, V., Moe, A., 2013a. Oil Industry Structure and Developments in the Resource Base: Increasing Contradictions? In: Godzimirski J.M. (Ed.), Russian Energy in a Changing World: What is the Outlook for the Hydrocarbons Superpower? Ashgate, Farnham, pp. 35–56.

Kryukov, V., Moe, A., 2013b. The Russian Oil Sector, in Alexeev M., Weber, S. (Eds.), Oxford Handbook of the Russian Economy. Oxford University Press. Oxford, pp. 341–262.

Law of the Russian Federation, 1992. N 2395-1 ‘O nedrakh’, including amendments as of 29 July 2017. http://base.garant.ru/10104313/

Lozano Maya, J.R., 2013. The US experience as a reference of success for shale gas development: The case of Mexico. Energy Policy 62, 70–78. https://doi.org/10.1016/j.enpol.2013.07.088

Lozano Maya, J.R., 2016. Looking through the prism of shale gas development: Towards a holistic framework for analysis. Energy Research & Social Science 20, 63-72. https://doi.org/10.1016/j.erss.2016.05.014

Malikov, A., 2015. Poligony_dlya_trudnoy_nefti. Inform devon. 20 May. http://iadevon.ru/news/articles/poligoni_dlya_trudnoy_nefti-2854/

Maugeri, L., 2013. The Shale Oil Boom: A US Phenomenon. Discussion Paper, Belfer Center for Science and International Affairs, Harvard Kennedy School. https://www.belfercenter.org/sites/default/files/legacy/files/draft-2.pdf

Mescherin A., 2013. Nedropol’zovanie v Rossii: vse podelili, prishla pora umnozhat’? Neftegazovaya Vertikal’ (7), 118–143.

Morozov, V., 2017. Perspektivy dobychi slantsevoy nefti v Zapadnoy Sibiri. Vernadskiy State Geological Museum, Russian Academy of Sciences, Moscow.

Morse, E., 2014. Welcome to the Revolution – Why Shale Is the Next Shale, Foreign Affairs, (May–June), 3–7.

MPR, 2014. O sostoyanii i ispol'zovanii mineral'no -syrevykh resursov Rossiyskoy Federatsii v 2013 godu, Moscow: Ministry of Natural Resources and Ecology.

MPR, 2015a. O sostoyanii i ispol'zovanii mineral'no-syrevykh resursov Rossiyskoy Federatsii v 2014 godu. Moscow: Ministry of Natural Resources and Ecology.

MPR, 2015b. V Rossiyskoy Federatsii budet sozdan Yediniy fond geologicheskoy informatsii. Press release. 19 June. http://www.mnr.gov.ru/news/detail.php?ID=141453&sphrase_id=959602

MPR, 2016. O sostoyanii i ispol'zovanii mineral'no -syrevykh resursov Rossiyskoy Federatsii v 2015 godu. Moscow: Ministry of Natural Resources and Ecology.

Neftegaz.ru, 2014. Burovoy krizis, ili zavody po proizvodstvu burovyh ustanovok nuzhdayutsya v gospodderzhke. 18 September. http://neftegaz.ru/news/view/130080-Burovoy-krizis-ili-zavody-po-proizvodstvu-burovyh-ustanovok-nuzhdayutsya-v-gospodderzhke

Neftegazovaya Vertikal’, 2010. Chto meshaet innovatsiam?. Neftegazovaya Vertikal’ (13/14), 54–60.

Neftegazovaya Vertikal’, 2015. VMSB v Rossii: pik blagopoluchia. Neftegazovaya Vertikal’ (13/14), 12–32.

Neftegazovaya Vertikal’, 2016. TRIZ: L’goty ne udalis’, nuzhny stimuli. Neftegazovaya Vertikal’(1/2), 58–64.

Nefteotdacha, nd. O kompanii. http://rmntk.ru/

Nikitin, N., 2014. Netraditsionnye i trudnoizvlekaemye: rentabel’noe osvoenie? Obzor dokladov uchastnikov soveschaniya v MPR RF po izucheniyu i osvoeniyu netraditsionnykh vidov i istochnikov uglevodorodnogo syr’ya. Neftegazovaya Vertikal’ (8), 32–42.

Panov, R. S., 2014. Sozdanie sistemy federal’nykh poligonov po netraditsionnym i trudnoizvlekaemym resursam. Presentation. Tomsk. 5 March. http://rosgeoportal.ru/association/materials/SitePages/downloads/t%D0%BEmsk05032014_08.pdf

Prusakov, V., 2017. K trudnym gorizontam. Neftegazovaya Vertikal’ (11), 44– 47.

Pumphrey, D., 2015. The impacts of shifting world energy markets on Arctic resource development, in: Young, O., Kim, J.D., Kim., Y.H., Hyung Kim (Eds.), The Arctic in World Affairs: A North Pacific Dialogue on the Arctic in the Wider World. Korea Maritime Institute, Busan, Republic of Korea, and East–West Center, Honolulu, Hawaii, pp. 249–278.

Railroad Commission of Texas, 2017. Oil and Gas Well Records. http://www.rrc.state.tx.us/oil-gas/research-and-statistics/obtaining-commission-records/oil-and-gas-well-records/

Regnum, 2017. Slantsevaya neft’ v Rossii: Nikakogo Zapada, tol’ko svoimi silami. 11 September. https://regnum.ru/news/2320114.html

RIA Novosti. 2017. Komarova: padenie neftedobychi v Yugre v 2016 g zamedlilos’ vpervye za 4 goda. 30 January. https://ria.ru/economy/20170130/1486773407.html

Rogtec, 2013. Bazhenovskaya svita: v poiskakh bol’shoy slantsevoy nefti na Verkhnem Salyme. Russian Oil and Gas Technologies. 27 August. http://rogtecmagazine.com/ru

Rogtec, 2017. V minprirody pridumali, kak ekonomicheski prostimulirovat’ osvoenie trudnoizvlekaemykh zapasov. Russian Oil and Gas Technologies. June. http://rogtecmagazine.com/ru

Rosneft, 2017. Rosneft and Statoil started pilot drilling as part of the development of Domanik sediments. Press release. 31 January. https://www.rosneft.com/press/news/item/185549/

Russneft’, 2017. PAO NK ‘Russneft’’ poluchila debit v 100 tonn iz bazhenkovskikh otlozhenii. Press release. 4 August. http://www.russneft.ru/i/press_release_lang/file_path_2365.pdf

Schlumberger, nd. Oilfield glossary. http://www.glossary.oilfield.slb.com/

Shpil'man, A.V., 2015. O printsipakh sozdaniya nauchnogo poligona «Bazhenovskiy» v Khanty-Maniyskom avtonomnom okruge – Yugra. Nedropol'zovanie 21 (1), 4–10.

Shpurov. I.V., 2017. Trudnoizvlekaemye zapasy Rossiyskoy Federatsii. Kriterii i otsenka, Problemy ekonomiki i upravleniya neftegazovym kompleksom. (7), 8-12.

Strategy, 2015. Strategiya razvitiya toplivno-energeticheskogo kompleksa Respubliki Tatarstan na period do 2030 goda. http://gossov.tatarstan.ru/fs/site_documents_struc/04zak1.pdf

Stulov, P., 2015. Bazhenovskiy poligon – put' k osvoeniyu resursov slantsevoy nefti v Khanty-Mansiyskom avtonomnom okruge. V.I.Shpilman Research and Analytical Centre for the Rational Use of the Subsoil, Khanty-Mansiysk.

Sychev, P., 2017. 'Tatneft'' v 2016 godu narastila dobychu nefti na 5.3 %do 28.6 mln tonn.. RBK. 10 January. http://www.rbc.ru/tatarstan/10/01/2017/58748abd9a7947825212c813

Troutman, T., 2009. Core repository, well log links, and resources. http://www.carbonates.us/cores.htm

Varlamov A., 2016. Bez novykh otkrytiy net buduschego. Neftegazovaya Vertikal' (20), 40–45.

Varlamov, A.I., Yasparov, O.S., Khlebnikov, P.A., Poroskun, V.I., Fortunatova, N.K., Skvortsov, M.B., Iutina, M.Yu., 2017. Kontseptsiya osvoeniya slantsevoy nefti v Rossiyskoy Federatsii. 6 April. On file with the authors.

Vercueil, J., 2014. Could Russia become more innovative? Coordinating key actors of the innovation system. Post-Communist Economies 26, 498–521.

Vin'kov, A., Mekhanik, A., 2017. Skvazhiny zhdut intellekta. Stimul.online. https://stimul.online/articles/interview/skvazhiny-zhdut-intellekta/

Yaschenko, I., Polischuk, Yu., Kozin, Ye., 2015. Trudnoizvlekaemye nefti: klassifikatsiy I analiz kachwestvennykh osobennostey. Oil & Gas Journal Russia (11), 64–70. http://ogjrussia.com/uploads/images/Articles/Nov2015/Geo2.pdf