“Domanik shale oil: unlocking potential”
Presentation Agenda

- Areas of Unconventional Resource potential within PJSC LUKOIL’s leasehold/licenses in Volga-Ural and Timan-Pechora provinces
- Results of Domanik Shale Studies by PJSC LUKOIL
- Properties comparison of Domanik shale and other well-known shale basins in North America
- Potential for implementation of the lessons learned during pilot studies of Domanik shale to successfully develop Domanik as an unconventional resource play
- Future steps: program of additional studies of Domanik Shale at PJSC LUKOIL’s license areas
- Main results of Bazhenov Shale Studies by PJSC LUKOIL
Volga-Ural and Timan-Pechora provinces: Unconventional Potential
Domanik deposits are the main oil source rocks for Timan-Pechora and Volga-Ural oil&gas provinces
Oil&Gas Potential of Domanik Deposits

- Republic of Tatarstan: over 330 targets have been tested with 44 cases of inflow
- Republic of Bashkortostan: over 100 t/day obtained within Belskaya depression areas
- Perm Oblast: 163 targets have been tested, with oil rate over 1 t/day obtained in 14 cases
- Republic of Udmurtia: most wells have been dry, 10 wells were wet, and 7 wells with oil inflow rate of 7 m³/day
- Samara Oblast: 120 targets of which 34 targets have produced oil. The maximum oil and water inflow rate of 55 m³/day has been obtained in the Domatovskaya area from the Buregsky horizon
- Orenburg Oblast: 34 targets of which 9 targets have produced oil. The maximum oil inflow rate over 100 m³/day has been obtained in the Tverdilovskaya area
- Water inflows were found in 43 cases within Samarskaya and Orenburgskaya areas
- Timan-Pechora province: oil inflow in 48 wells, Qo of up to 88 t/day

Oil-gas saturation of Domanik deposits has been confirmed by number of well tests throughout the development area
**Areas of Unconventional Hydrocarbon Resource Potential within PJSC LUKOIL’s License Areas in Russia**

<table>
<thead>
<tr>
<th>No.</th>
<th>Field</th>
<th>Formation</th>
<th>Formation parameters</th>
<th>Reserves, thous. t</th>
<th>Kp</th>
<th>Kos</th>
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<tr>
<td>1</td>
<td>Isanevskoye</td>
<td>Fr-T</td>
<td>0.1</td>
<td>178</td>
<td>0.8</td>
<td>112</td>
</tr>
<tr>
<td>2</td>
<td>Rakinskoye</td>
<td>Sarg</td>
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<td>160</td>
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<td>11</td>
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<tr>
<td>3</td>
<td>Tyushevskoye</td>
<td>Domanik</td>
<td>0.09</td>
<td>22</td>
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<tr>
<td>4</td>
<td>Stretenskoye</td>
<td>Mendym</td>
<td>0.12</td>
<td>98</td>
<td>0.7</td>
<td>31</td>
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</table>

**Domanik formation oil fields within the Perm Krai territory**

**Domanik formation oil fields within the Timan-Pechora province**

**Domanik formation oil fields within the Samara Oblast territory**

**Domanik limits within Komi Republic and Nenets Autonomous Okrug (Timan-Pechora province)**

**Domanik limits within the the Perm Krai territory (Volga-Ural province)**

**Domanik limits within the Samara Oblast territory (Volga-Ural province)**

**Domanik reserves (A + B + C₁) of PJSC LUKOIL amount to 1.5 mln t**
Results of Domanik Shale Studies by PJSC LUKOIL
Sedimentation Environment During the Domanik Age In Volga-Ural and Timan-Pechora Provinces

The Domanik formation within Volga-Ural and Timan-Pechora Provinces covers ~232 000 km²
Always moving forward!

Total Organic Carbon (TOC) Map of the Domanic Formation

Within the Perm Krai territory (Volga-Ural province)

- Over 900 wells

Samara Oblast (Volga-Ural province)

- TOC > 5%

Komi Republic and Nenets Autonomous Okrug (Timan-Pechora province)

- TOC content was determined based on Geochemical data and core analysis in 4 wells
- Where no core analysis was available, TOC was determined based on TOC = f(GR), which could lead to major errors

- Within Domanik formation there are large areas where TOC ranges from 2 to 5% and occasionally up to 23%
Organic matter of Domanic formation is predominantly of type II kerogen.

Upper and lower deposits contain organic matter of type II and II + III.
The estimated oil generation potential is good and very good;
Geochemically, domanik deposits are promising as potential sources of shale oil and gas.
Thermal Maturity Maps of Domanik Shale (based on Vitrinite Reflectance)

Domanik horizon catagenetic zoning maps based on geochemical studies of wells show promising areas ($Ro \geq 0.6$) in all the three regions.
TOC and $R_o$ Comparison of Domanik Shale of Perm Krai and US Shale Formations

In some areas Domanik has TOC of 23 %

TOC and Thermal Maturity of Domanik Shale is comparable and as good as commercial shale deposits in the USA
### 199 Andreevskaya

<table>
<thead>
<tr>
<th>Номер</th>
<th>Литология</th>
<th>Геологический возраст D f</th>
<th>Тип</th>
<th>Отбор образца</th>
<th>Глубина отбора образца</th>
<th>Длина капиллярной вытяжки, мм</th>
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<tbody>
<tr>
<td>1</td>
<td>D3mn</td>
<td>Dolomites of glauconitic dolomites with rare argilite layers</td>
<td>Dolomite</td>
<td>2454,42</td>
<td>2271,93</td>
<td>2272,03</td>
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<tr>
<td>2</td>
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<td>Dolomites of glauconitic dolomites with rare argilite layers</td>
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### 266 Zabrodovskaya

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### 296 Pavlovskaya

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<td>Dolomite</td>
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### 200 Andreevskaya

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<th>Тип</th>
<th>Отбор образца</th>
<th>Глубина отбора образца</th>
<th>Длина капиллярной вытяжки, мм</th>
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<td>2272,35</td>
</tr>
</tbody>
</table>

**Domanik formation rocks feature high saturation**
Oil saturation of shale formations should be calculated taking into account oil fraction adsorbed by organic matter:

\[ \text{OSI} = \frac{S_1}{\text{TOC}} \times 100 \]

OSI – oil saturation index, mg/g TOC; \( S_1 \) – mobile oil, mg/g; TOC – total organic carbon, %

**Jarvie Oil Saturation Index**

Potential producing zone

Non-producing zone

**Free oil, mg/g TOC**

**Total organic carbon (TOC), %**

**Depth, ft**

**Example of oil saturation distribution based on well-logging at Bakken field**

Core analysis of LUKOIL PERM LLC wells shows that unconventional reservoirs has potential for production.
Mineral composition of domaniks within Volga-Ural and Timan-Pechora oil and gas provinces

The prevailing mineral composition of domanik shale is similar to one of the U.S. largest Eagle Ford shale deposits and is promising for good reservoir quality properties and efficient multi-stage hydrofracturing.
Fracturing

Due to extremely low permeability it is required to maximize the contact area between the matrix and highly permeable filtration channels by detecting natural fracturing areas and creating artificial fracturing areas.

Shale reservoir fluid movement

Many faults result in favorable conditions for domanik development
Comparison of Domanik shale and other well-known shale basins in North America
### Domanik Shale vs. Major US and Canadian Unconventional Basins (Kimmeridge Energy, 2014)

<table>
<thead>
<tr>
<th>Basin</th>
<th>New Albany (US)</th>
<th>Bakken (US)</th>
<th>Exshaw (US/Canada)</th>
<th>Duvernay (Canada)</th>
<th>Domanik (Russia)</th>
<th>Eagle Ford</th>
<th>Woodford</th>
<th>Wolfcamp</th>
<th>Kaliningr ad</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age</strong></td>
<td>Illinois Basin</td>
<td>Williston Basin</td>
<td>WCSB</td>
<td>WCSB</td>
<td>Timan-Pechora</td>
<td>Volga-Ural</td>
<td>Maverick Basin</td>
<td>Anadarko Basin</td>
<td>Delaware Basin</td>
</tr>
<tr>
<td><strong>Area of mature source mass (mln. acres)</strong></td>
<td>6</td>
<td>14</td>
<td>65</td>
<td>49</td>
<td>50</td>
<td>47</td>
<td>11.7</td>
<td>9.6</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Kerogen type</strong></td>
<td>III</td>
<td>II</td>
<td>II</td>
<td>II</td>
<td>III &amp; I</td>
<td>II</td>
<td>II</td>
<td>III</td>
<td>III/III</td>
</tr>
<tr>
<td><strong>Sedimentation environment</strong></td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
<td>Marine, anoxic</td>
</tr>
<tr>
<td><strong>Average content. Corg (%)</strong></td>
<td>6</td>
<td>19</td>
<td>10</td>
<td>6</td>
<td>4</td>
<td>87*</td>
<td>4.7</td>
<td>6</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Hydrogen index (mg/g TOC)</strong></td>
<td>450</td>
<td>625</td>
<td>500</td>
<td>590</td>
<td>600</td>
<td>500–450*</td>
<td>650</td>
<td>375</td>
<td>450</td>
</tr>
<tr>
<td><strong>Maturity (Ro %)</strong></td>
<td>0.85</td>
<td>0.80</td>
<td>0.90</td>
<td>1.25</td>
<td>0.80</td>
<td>0.75*</td>
<td>0.74</td>
<td>1.50</td>
<td>0.90</td>
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<tr>
<td><strong>S1 (mg HC/g rock)</strong></td>
<td>4.7</td>
<td>12.0</td>
<td>4.3</td>
<td>1.6</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
<td>4.8</td>
</tr>
<tr>
<td><strong>HC potential (S1 + S2)</strong></td>
<td>45</td>
<td>162</td>
<td>57</td>
<td>40</td>
<td>35</td>
<td>32</td>
<td>30</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Generation potential of basin (MMbbl. eq.)</td>
<td>143,469</td>
<td>415,613</td>
<td>658,023</td>
<td>1,242,670</td>
<td>2,491,571</td>
<td>1,911,639</td>
<td>&gt;800</td>
<td>280</td>
<td>580</td>
</tr>
<tr>
<td>Specific generation potential (bbl./acre)</td>
<td>25,243</td>
<td>29,932</td>
<td>10,049</td>
<td>25,145</td>
<td>50,150</td>
<td>40,717</td>
<td>4600–7500+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quartz content (%)</td>
<td>31–49 %</td>
<td>20–68 %</td>
<td>7–82 %</td>
<td>3–54 %</td>
<td>35–95 %</td>
<td>10–15 %</td>
<td>2–40 %</td>
<td>41–75 %</td>
<td>20–50 %</td>
</tr>
<tr>
<td>Carbonate content (%)</td>
<td>12–36 %</td>
<td>20–60 % (in Middle Bakken)</td>
<td>20–60 %</td>
<td>18–90 %</td>
<td>0–40 %</td>
<td>70 %*</td>
<td>10–90 %</td>
<td>2–14 %</td>
<td>10–60 %</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>12 %</td>
<td>2–10 %</td>
<td>4–8 %</td>
<td>6–10 %</td>
<td>13</td>
<td>9–12 %*</td>
<td>4–15 %</td>
<td>3–9 %</td>
<td>2–10 %</td>
</tr>
<tr>
<td>Permeability (mD)</td>
<td>0.005–0.01 mD</td>
<td>Abnormally high formation pressure</td>
<td>Abnormally high formation pressure</td>
<td>Abnormally high formation pressure</td>
<td>Below normal</td>
<td>Abnormally high formation pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Consistent with survey results of wells 199, 200 of Andreevsky, 266 Zabrodovsky and 296 Pavlovsky fields
* Consistent with survey results of wells in Timan-Pechora province

**Average parameters of Domanik Shale are similar to the shale deposits in the US and Canada that are currently being successfully developed, confirming the promising potential as an unconventional resource play**
HC Potential Estimation of Domanik Formation by “Volumetric-Geochemical” Method

Hydrocarbon yield of organic matter vs. maturity, mg/g

$S \ h \ C_{org} \ \rho \ \lambda = \text{HCP}$

$\rho_{om} = 1.3 \text{ g/cm}^3$

When evaluating Unconventional Resources, TOC and Thermal Maturity should be taken into account
Probabilistic Assessment of Domanik Formation Resources within the Perm Krai Territory

<table>
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<tr>
<th></th>
<th>P 90</th>
<th>P 50</th>
<th>P 10</th>
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<tbody>
<tr>
<td>Thickness</td>
<td>$D_{3_{dm}}$</td>
<td>$D_{3_{dm+mn}}$</td>
<td>$D_{3_{dm+mn}}$</td>
</tr>
<tr>
<td>Area</td>
<td>Extent area of shallow marine shelf (SMS) facies and uncompensated basins (UCB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOC Organic matter content, %</td>
<td>Based on GR dependence, $C_{org} = f(GR)$</td>
<td>According to experts, based on one-time geochemical surveys</td>
<td>According to experts, based on one-time geochemical surveys</td>
</tr>
<tr>
<td>HC generation, mg/g organic matter</td>
<td>Based on general dependence</td>
<td>Based on dependence for domanik organic matter</td>
<td>Based on dependence for domanik organic matter</td>
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<tr>
<td>Amount of expelled HC</td>
<td>Based on one-time geochemical surveys (70 %)</td>
<td>Based on one-time geochemical surveys (70 %)</td>
<td>Based on common value (50 %)</td>
</tr>
<tr>
<td>Resources, bln t</td>
<td>0.78</td>
<td>3.57</td>
<td>5.95</td>
</tr>
</tbody>
</table>

Even by pessimistic assessment, Domanik contains huge amounts of hydrocarbons. It is reasonable to plan and conduct additional pilot studies to calibrate the methods of high grading the areas and evaluation of recoverable reserves per well.
Potential for implementation of the lessons learned during pilot studies of Domanik shale to successfully develop Domanik as an unconventional resource play
Methodology to Develop Successful Well Program

**Geochemical survey**
- HC classification, identification of oil-gas accumulation zone and paleographic environment, organic matter distribution over rocks under study, obtaining the main information on organic matter (generation potential, kerogen type, maturation), revision of domainik resource potential considering vertical migration

**Lithological character of the section**
- Opening, dip and strike azimuth, fracture intensity, mineral composition, analysis of facies, study of pores and their interior structure, composition, presence of kerogen, presence of microporosity, study of fluid influence (water, acids, fluids for oil recovery increase) on mineral aggregates

**Petrophysical survey**
- Determination of ultra-low permeability of unconventional reservoirs, pore distribution up to nanosize, study of reservoir quality properties, residual water and oil by nuclear magnetic resonance

**Geomechanical survey**
- Determination of rock stress-strain properties for hydrofracturing design and horizontal well drilling. Determination of Young's modulus, Poisson ratio, pore compressibility, tensile and compression strength under formation conditions

**For efficient localization of highly productive zones and successful well locations, these parameters should be determined based on seismic exploration that in turn should be matched with regional surveys, core analysis and well-log data.**
Future steps: program of additional studies of Domanik Shale at PJSC LUKOIL’s license areas
The domanik-type deposit study program has been drawn with required surveys indicated. Candidate wells have been selected in the most promising zones.
Conclusions (Domanik shale)

- Domanik deposits are understudied as a source of Unconventional Resources
- Domanik deposits are prospective as a target for shale oil exploration
- Comprehensive program of additional studies and development of Unconventional Resources in LUKOIL’s license areas has been established
- It is advisable to allocate experimental sites for testing of unconventional technologies to develop the Domanik formation in a cost-efficient manner
Main results of Bazhenov Shale Studies by PJSC LUKOIL
Mid-Nazym field in South Kanty-Mansiysk

- **Start year**: 1980
- **Operator**: AO RITEK
- **Share**: 100%
- **Current stage of development**: Pilot projects
- **Information about extraction tax raise**: Bazhenov deposits, Tyumen deposits, September 2013
Scenarios for selection of effective oil-saturated thickness in the sediments of the Bazhenov formation

<table>
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<th>Field:</th>
<th>Em-Egovskaya</th>
<th>Stone and East-Stone</th>
<th>Mid-Nanzym (RITEK)</th>
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<tr>
<td>Scenarios</td>
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<tr>
<td></td>
<td>Effective thickness includes the carbonate-silica layer thickness with fractures</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \text{Heff} = H \text{carb-silic}; \ \text{Кп.вт} = f (\text{Кп общ, Кп.блок}), \ \text{Кн} = 0,9 -0,95 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effective thickness includes thickness of carbonate layers + total matrix thickness:</td>
<td></td>
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<tr>
<td></td>
<td>( \text{Heff} = H_{\text{tot}} = \text{Heff мат + Hcarb-silic}; \ \text{Кп.вт} = f (\text{Кп общ, Кп.блок}), \ \text{Кп матр} = \text{Кп.тр} = 0,1-0,5% , \ \text{Кн} = 0,9 -0,95 )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effective thickness includes thickness of fractured carbonate layers + matrix bordering the layer:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>( \text{Heff} = H_{\text{carb-silic}} + n \times \text{Hмат}; \ \text{Кп, Кн – also} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Effective thickness includes thickness of the selected porous-fractured, cavernous fractured and fractured reservoirs (based on wireline)</td>
<td></td>
<td></td>
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<td>( \text{Heff} = H_{\text{fract}} + H_{\text{cavern.fracture}} + H_{\text{pore.fracture}}; \ \text{Кп,ср}=(\text{Кп,карб-крем} \times \text{Нкарб-крем} + \text{Кп.тр} \times \text{Нтр}) / \text{Нобщ} )</td>
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</table>

Total effective thickness included

\(1/3\) of the total thickness from Bazhenov, \(\text{Кп} \approx 8\% , \ \text{Кн} = 0,9\)
Characteristics of the Bazhenov formation

**HC resources in the Bazhenov formation**

- **Residue of organic matter – kerogen**
  (average content 23.3% of rock vol.)
- **Light oil**
  product generation of organic matter

**Oil+kerogen containing rocks**

- **Micro-fractured reservoir (matrix)**
  Doesn’t work without stimulation
- **Macro-fractured reservoir**
Almost no permeability deters from developing the Bazhenov formation through conventional methods

Main steps:

✓ Analysis and mapping of high-potential areas (fracture zones);
✓ Drilling of horizontal wells with long laterals (1000-1500m and more);
✓ Multistage hydraulic-fracturing to form multiple fractures and/or system of natural fractures;
✓ Development and application of techniques to prevent the rapid decline in oil and gas rates (60-80% in the first 12 years).
   Implementation of thermogas impact.
Appraisal drilling of horizontal wells with multi-stage fracturing of the Bazhenov formation

Well 100H:
- Goal – confirm productivity potential
- Drilling in fractured zone;

Well 101H:
- Goal – confirm productivity potential

Always moving forward!
Results of drilling and completion of Well 100H

- Horizontal length – 1000m
- Number of stages - 6;
- Proppant volume – 197t (fracturing fluid vol. – 1500m³)
- Commissioned on 30/12/2013 with a initial daily rate of 80t/day
Fracture propagation during multi-stage fracturing and flow profile in the wellbore

45% of the inflow into the wellbore comes from the 4th frac stage (32m$^3$/day)
Thermogas Impact (TGI) on the Bazhenov formation deposits

When implementing TGI oil production consists of 3 components:
1) Oil production from the drained area;
2) Oil production by pyrolysis of kerogen in the drained areas;
3) Oil production by thermodynamic impact on non–drained area (matrix)
Results of Bazhenov formation core material studies

- Evaluation of kerogen and carbonate content in samples (24%)
- Kinetics of kerogen decomposition (29%)
- HC expulsion in the autoclave (9%)
- Geomechanical rock properties from core samples (12%)
- Filtration experiments (26%)

Pressure 200atm
Temperature 350°C
Gas (CH4,…) 50..60 m³

1m³ of rock
Oil 50..80 litters
Mxt. gas
Synt. oil

Air

Distribution of volume of work on technical studies

Pressure 200atm
Temperature 350°C
Results of air injection experiments

**Fractional composition and oil physical properties analysis**

- Oil density decrease.
- Fractional composition altered toward lighter fractions.

<table>
<thead>
<tr>
<th>Oil physical properties (well 3000)</th>
<th>before TGI</th>
<th>after TGI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil density (at T = 20 °C)</td>
<td>837 kg/m³</td>
<td>800 kg/m³</td>
</tr>
</tbody>
</table>

**Composition and evolution of GOR analysis**

- Doubled HC gases
- Increased fraction of CO2 and N2 in produced gas.
- No oxygen in produced gas.

**Gas composition in production wells**

- CH₄
- C₂-C₄
- CO₂
- N₂

**Temperature profile in well 219**

Temperature measurements made during the implementation of the second cycle of the experiment showed that temperatures rose to 127°C, i.e. increased by 20°C relative to T₀ (initial)

Oil density decreased from 837 to 800 kg/m³, oil dynamic viscosity from 6.26 to 1.9 mPa*s.

All reactive wells experienced increase formation pressure from 20 to 100 atm.
Results of thermogas impact (TGI) technology

FIRST PHASE
Well №219. Mid-Nazym field:

- Injected more than 7 million m³ of air
- Estimated additional oil production – 23,000 tons
- No O2 in produced gas, indicative of oxidation processes
- Increased fraction of Co2 and N2 in the produced gas
- Oil density decreased by 5%
- Increased fraction of lighter components in crude production
- Increased volume of produced HC gas
- Special well drilling
- Primary core analysis confirmed the passage of the thermal front

PERSPECTIVES
- Displacement chamber oxidation;
- Core research to assess the spread of oxidation reactions
## Development perspectives of thermal gas impact technology

### SECOND PHASE

Well 210.  
Mid-Nazym field, South Khanty-Mansiysk.  
- Commissioning – February 2015  
- Injected more than 1.2 million m³ of air  
- Horizontal well 100H with multistage fracturing

### Challenges

- Project implemented on old sites  
- Unsatisfactory condition of wells

### THIRD PHASE – IMPROVING EFFICIENCY

- Selection of optimal well location and well design  
- Mode optimization of the stimulation (Air injection and water-air ratio)  
- Cyclical impact on the reservoir  
- Use of air enriched with oxygen
## Thermal gas impact technology road map

<table>
<thead>
<tr>
<th></th>
<th>2009</th>
<th>2015</th>
<th>2017</th>
<th>2019</th>
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</thead>
<tbody>
<tr>
<td>Phase I</td>
<td>TGI Test</td>
<td>Test TGI on site with horizontal drilling and multi-stage fracturing</td>
<td>New location with special wells for TGI</td>
<td>Commercial implementation of TGI</td>
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<td>TGI Regulation and process management</td>
<td>Cyclic process</td>
<td>Experimental area for TGI with horizontal drilling and multi-stage fracturing</td>
<td>Injection of oxygen enriched air</td>
</tr>
<tr>
<td></td>
<td>Equipment tests for TGI</td>
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</tbody>
</table>

- **2009**: TGI Test
- **2015**: Test TGI on site with horizontal drilling and multi-stage fracturing
- **2017**: New location with special wells for TGI
- **2019**: Commercial implementation of TGI
Conclusions (Bazhenov Shale)

Experimental work is continued at the TGI sites. Evidence of oxygenation processes are obtained during the experiments.

Implementation of LUKOIL’s program to optimize the development technology will effectively unlock resources and increase production capacity.
THANK YOU FOR YOUR ATTENTION