# Enhanced Oil Recovery in the fields of Rosneft (onshore)

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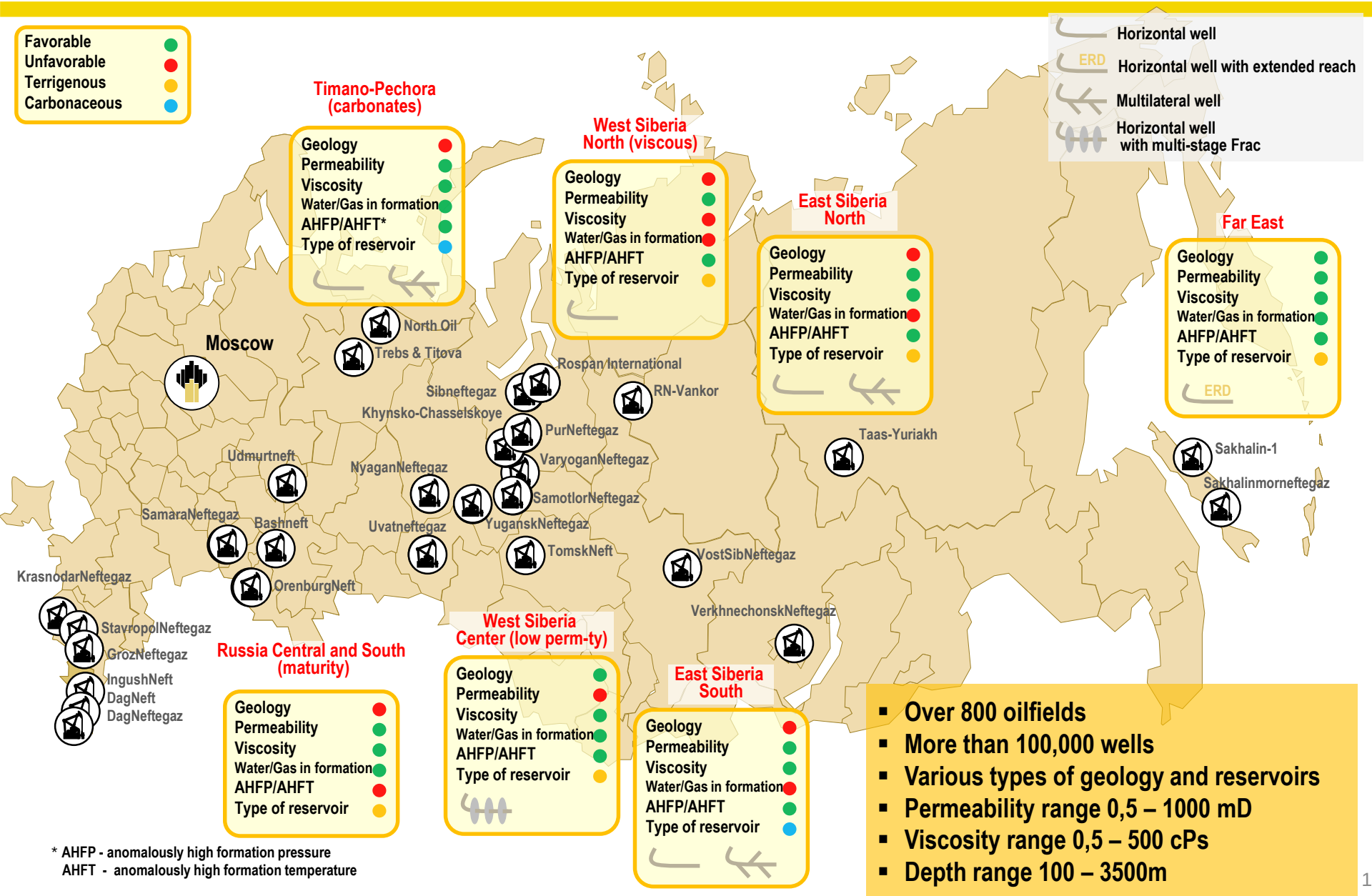
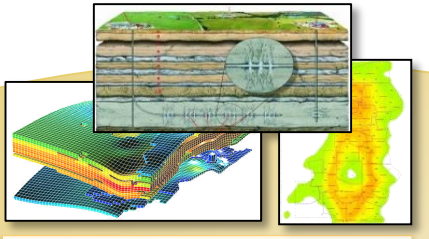
# Rosneft operates in various geological setting



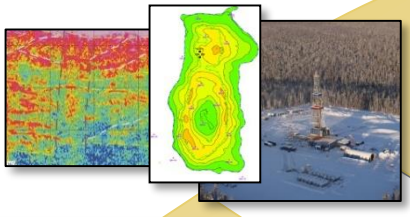

- Over 800 oilfields
- More than 100,000 wells
- Various types of geology and reservoirs
- Permeability range 0,5 – 1000 mD
- Viscosity range 0,5 – 500 cPs
- Depth range 100 – 3500m

* AHFP - anomalously high formation pressure
AHFT - anomalously high formation temperature

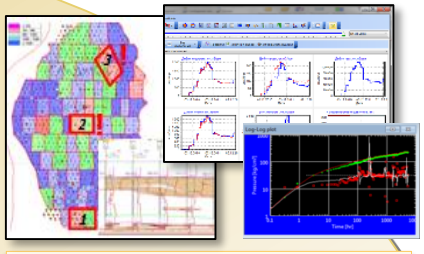
# Existing EOR process



Simulation model



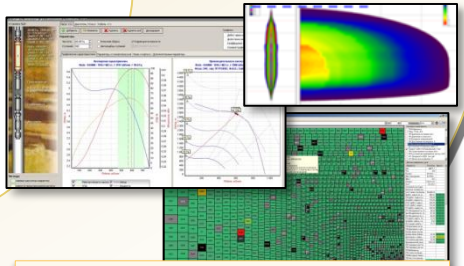
Geological Model



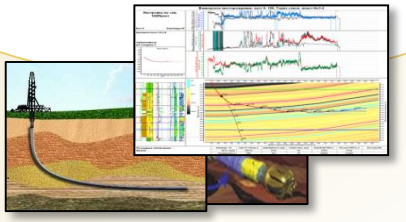
Development analysis, problem zones ranking

## Life Cycle Stages


Monitoring and planning

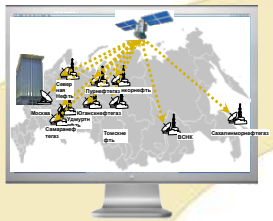


Technology design, Potential estimation, Ranking



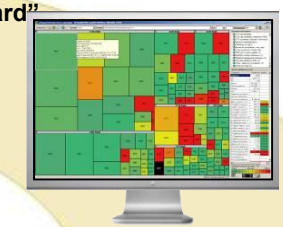
Project implementation (including real-time geosteering drilling of drilling)

# Company's consolidated information area
# Development and production monitoring and management system



Remote monitoring and engineering support for drilling of complex wells
Geosteering

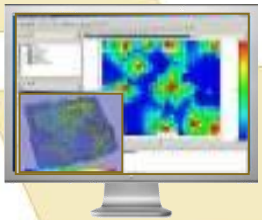
RN-Dobycha (RN-Production)
Software solution "Electronic Checked Board" (on-line control of well-stock indicators)



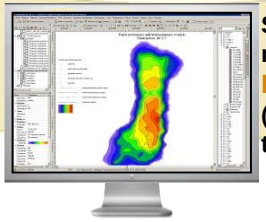
Rosneft-Wellview
Software solution (monitoring and analysis of artificial list well-stock)

**TPMSYS** ™

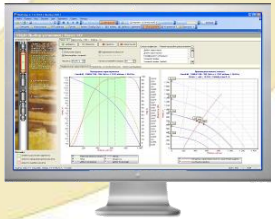
Total Production Management System



RN-KIM hydrodynamic simulation complex (forming of development systems and completion type)



Software solution for monitoring and planning of RN-KIM complex (remaining reserves, real-time forecast of activities)



RosPump
Software solution (downhole equipment selection)

## ADVANTAGES:

- Single database
- Single software line for geology, simulation, production and well monitoring
- 15 Rosneft's software packages developed with best international and national teams
- On-line well control and monitoring

# RN-KIN – monitoring tool for EOR efficient decision-making

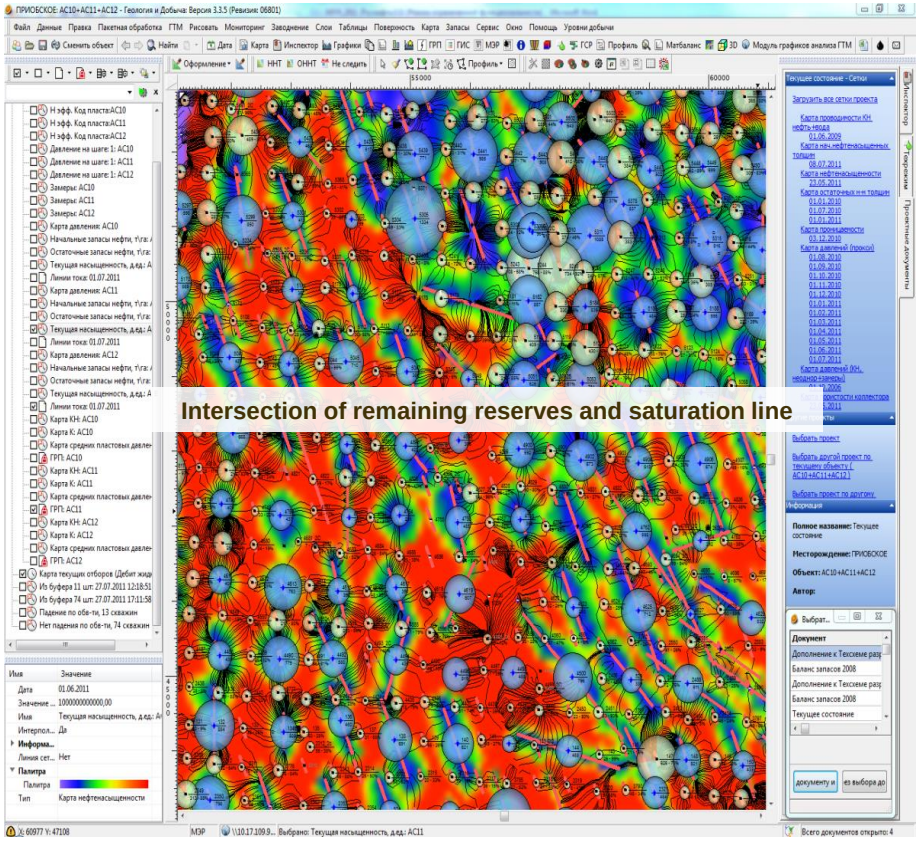
**RN-KIN** – is a large-scale software package for Reservoir Engineers designed on the “All-in-one” basis covering **more than 60 RE modules**.

**Software features**: immediate access and analysis of any geological and technology information from database
(including daily reading received from downhole equipment)

- **The key objective when designing EOR** – is to localize remaining reserves and identify no-flow areas
- **The crucial thing is to find a balance** between complexity/labour-consuming technique (or model) and the quality/ efficiency of calculation. Quite often efficiency of calculation with permissible variation is of higher priority than the quality.

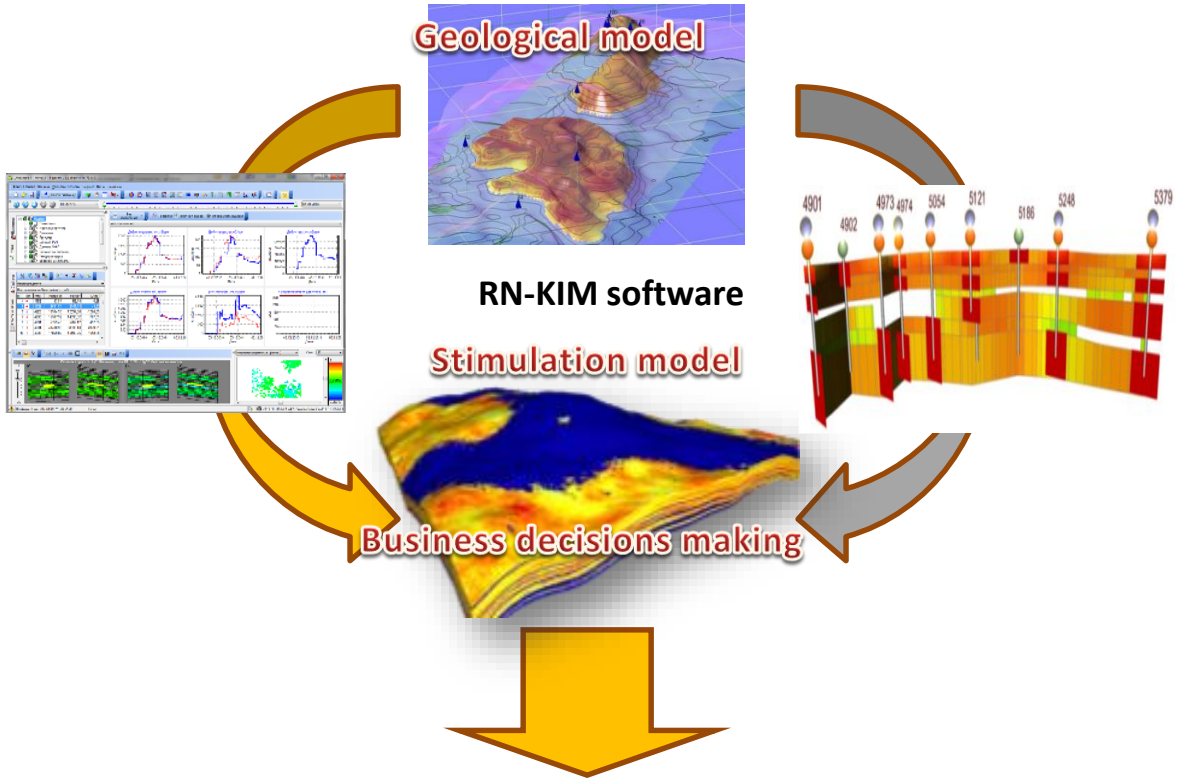
### A series of standard and unique engineering capabilities:

| Analysis Section | Timing | Note |
|---|---|---|
| DISPLACEMENT CHARACTERISTICS | 10 sec | Instantaneous analysis and reserves recovery forecast for any zone of the field |
| MATERIAL BALANCE | 5-10 min | Calculation of materials balance of the deposit (with adjustment), express planning of reservoir-pressure maintenance activities |
| SELECTION OF DEVELOPMENT SYSTEMS | 15 min | Express selection of standard development systems for the new deposit with feasibility study ranking for multivariant computation (considering completion including horizontal with multistage frac) |
| PROXY MODEL | 20-30 min | Building of 2D hydrodynamic proxy-model (with adjustment) to localize reserves, analyze resources energy state and to suggest solutions. |
| MESH ANALYSIS | 10 min | Mesh screening and analysis, formation of mesh operation mode, automated ranking |
| DISPLACEMENT FRONT | 3 min | Building the map of injection agent displacement front for express-analysis and activities planning |
| MAP BUILDING, SMART MAPS | Several minutes | Module for building geological maps and flow charts from data bases with math operations. Building smart maps (problem zones delineation) |
| BASE PRODUCTION AND WELL INTERVENTION | 5 min (large field) | Base production and well intervention factor analysis, localization on the wells map indicating problem zones and production losses |
| DYNAMIC WELL TEST | 15 min | Dynamic well test planning module (smart support grid) and express interpretation of the surveys performed |
| RESERVES AUDIT | 30-60 min (large field) | Reserves audit for SPE / SEC / RF categories |




RN-KIN allows to efficiently analyze the development status and to plan the required activities

# RN-KIM – computation tool for complex solutions in development




## Set of modeling tools (RN-KIM)

- Application programs package for building, calculation and analysis of geological and hydrodynamic models of full-size field models;
- Enables to make informed business decisions during field development planning both at the initial and late stages;
- Contributes to the Company's information security and allows to be independent from foreign simulation software;
- Contains a series of innovative developments designed and optimized to meet the specific requirements of Rosneft fields;
- Successfully passed certification tests. Intellectual property of Rosneft. The software is protected by the relevant certificates of the state registration.

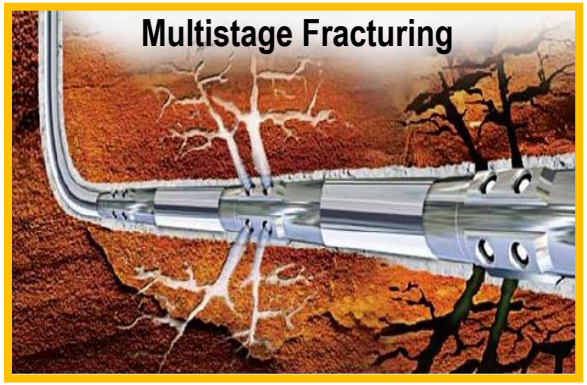
| Target business processes of RN-KIM | |
|---|---|
| **Greenfields** | **Brownfields** |
| • Selection of development system, including a possibility of complex completion and multivariant calculations<br>• Integral levels and indicators<br>• Design Project for the State committee on reserves | • Production and field development optimization<br>• Design documents update<br>• New technology verification<br>• Analysis and selection of wellwork and workover activities |

# EOR technology overview

| TYPE OF RESERVES | TECHNOLOGY |
|---|---|
| ***Greenfield*** | **Surveys and smart technology:**<br>▪ Up-to-date techniques (high-accuracy logging methods and dynamic well test, microseismic surveys, geomechanics, etc.)<br>▪ Smart wells (oilfield automation, high-accuracy wireless MWD)<br>▪ Remote drilling control (real-time geosteering) |
| **LOW-PERMEABLE** | **Hydraulic fracturing (Frac):**<br>▪ High-volume frac; multi-zone frac; thin barriers frac<br>▪ Foam-nitrogen and surfactant frac; increased conductivity frac or increased carrying capacity of gel<br>▪ Ultralow-permeable reservoirs fracturing with high flow (Hybrid, Slickwater)<br>▪ Directional frac in injection wells |
| **BELOW THE GAS CAP** | **Drilling and completion:**<br>▪ Dual completion (involving low-yield non-target formations into development)<br>▪ Horizontal completion with multistage frac<br>▪ Multi-hole (drain-hole) drilling (4-6 level of completion based on TAML)<br>**Drilling and completion:**<br>▪ Horizontal wells drilling<br>▪ Smart completion (bottom-hole inflow and pressure control) |
| ***Brownfield*** | **Physical and chemical:**<br>▪ New squeeze cementing and bottom hole treatment technology, loose ground cementing technology, new well-killing technology<br>▪ Smart water flooding - ASP, low-salinity flooding, thermo polymers (BrightWater), stiff EOR (nonsludging, colloidal polymeric systems), etc.<br>▪ Other tertiary technologies (water gas and thermal gas treatment) |
| **HIGHLY WATERED** | **Hydrodynamic methods:**<br>▪ Water flooding management (change of flow direction, sampling forcing, unconventional water flooding)<br>**Sidetracks:**<br>▪ Sidetrack kickoff and horizontal sidetracks (well stock recovery, development of non-draining bypassed hydrocarbons) |
| **HIGH VISCOSITY** | **Thermal methods:**<br>▪ Steam/hot water injection;<br>▪ SAGD (steam assisted gravity drainage)<br>▪ Steam Flooding |

# Efficiency improvement of complex greenfield development

# Technologies used for Greenfields development

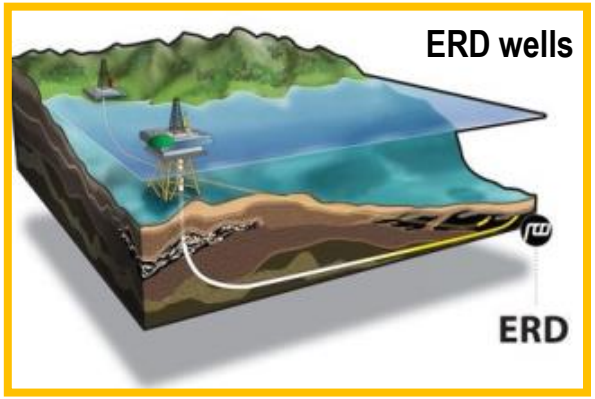



**HORIZONTAL WELLS DRILLING WITH MULTISTAGE FRACTURING**

- Historically noncommercial HTR reserves development
- Different completion types
- Horizontal section wells about 1000-2000m, about 20 fractures
- Two-casing wells drilling


**MULTIRATERAL WELLS**

- Heterogenous reservoirs (with WOC/GOC) and carbonates development
- Efficient drawdown while production to avoid water or gas blowout
- 2-5 TAML levels
- Number of laterals 2-10

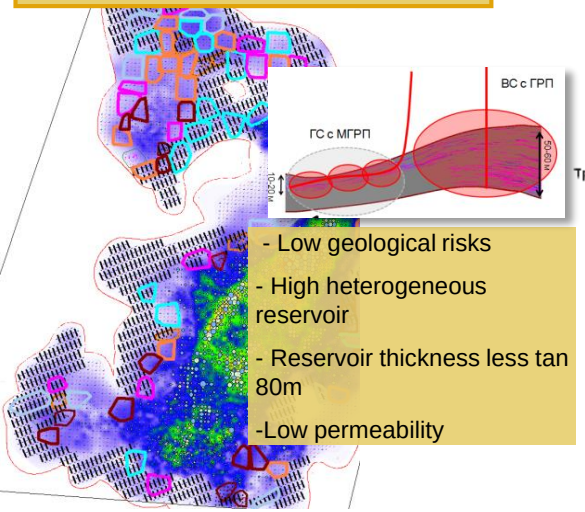



**ERD WELLS**

- Fields with surface facilities limitation, offshore fields and etc. development
- CAPEX reduction (onshore pads instead of offshore platforms)
- Successful drilling ERD well about 13,500m length with 3,000m horizontal section.

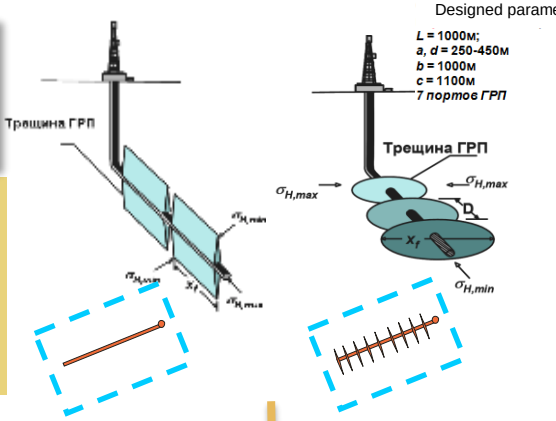
# Enhanced oil recovery system in low permeable reservoirs

## 1. Zone selection for horizontal wells drilling

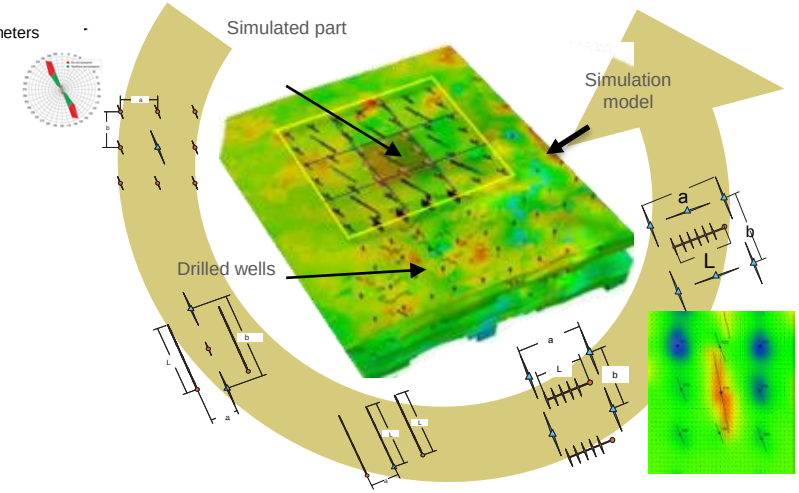



- Low geological risks
- High heterogeneous reservoir
- Reservoir thickness less tan 80m
- Low permeability

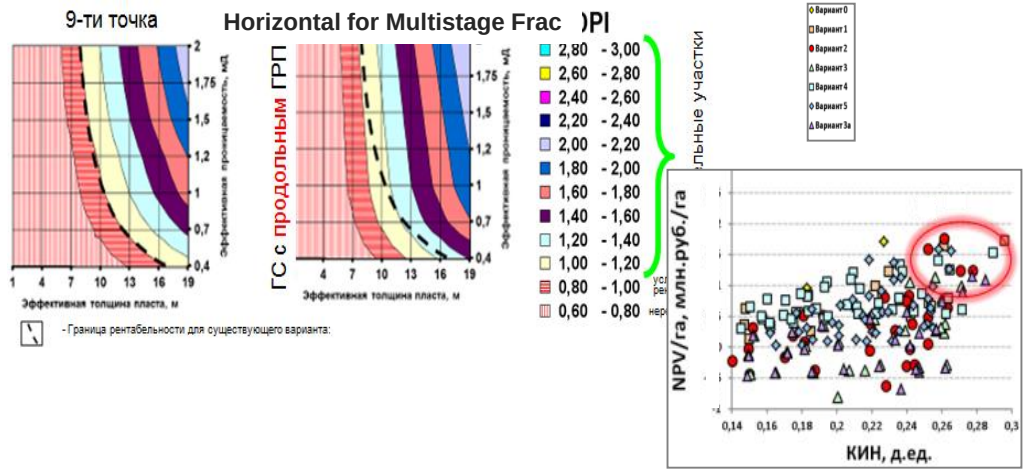
## 2. Optimal horizontal wells completion and design



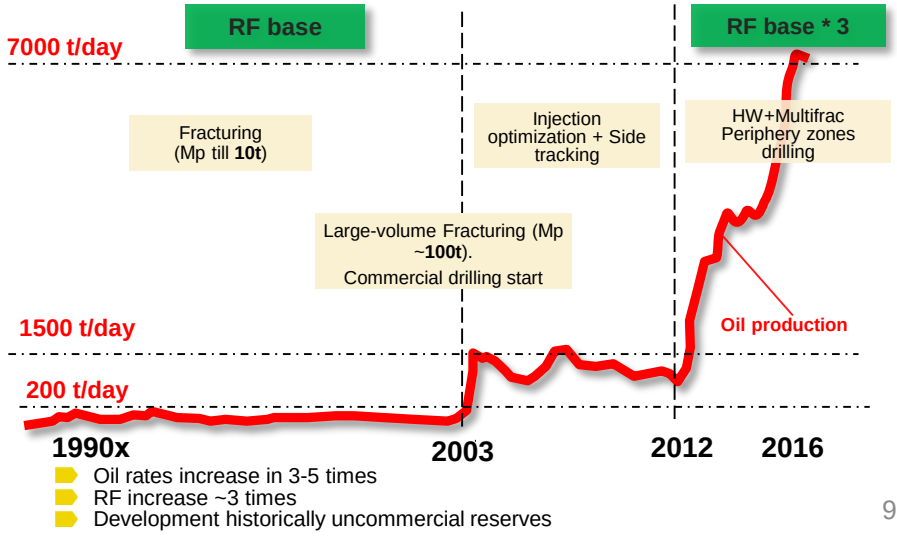

## 3. Simulation modeling (150+ calculations)




## 4. Optimal development scenario searching and risk analysis




## 5. Realization (Oil recovery increase example)

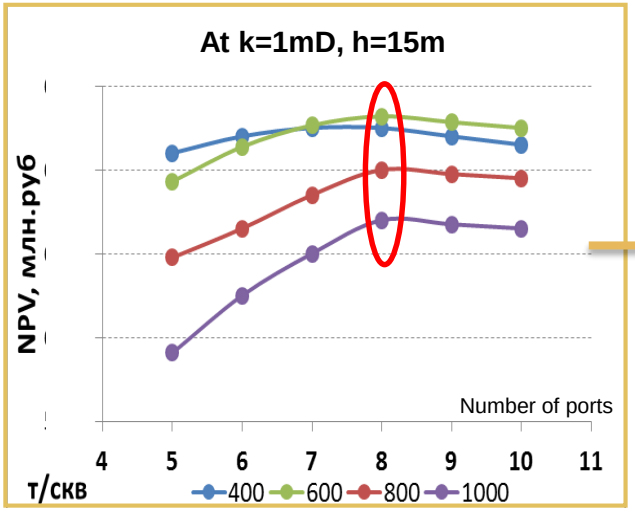


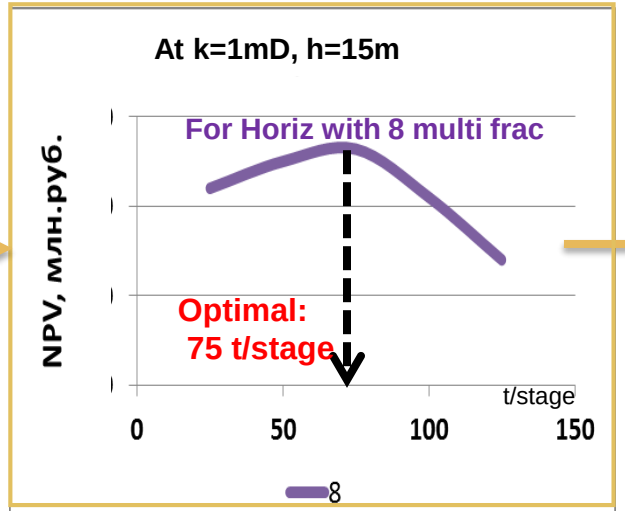

- Oil rates increase in 3-5 times
- RF increase ~3 times
- Development historically uncommercial reserves

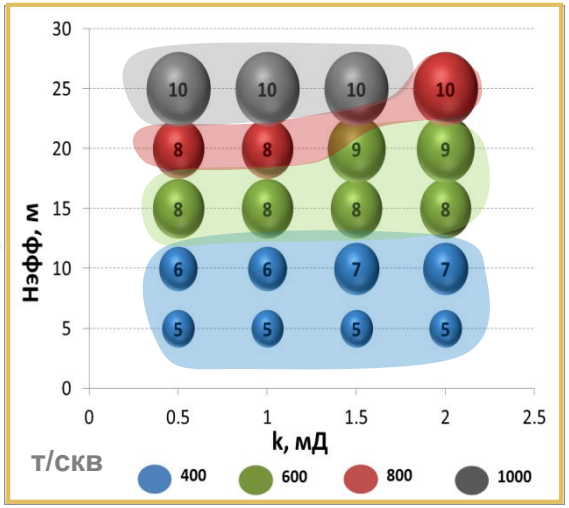
# Solutions for further optimization of horizontal well completion technology with multistage frac

**1. Optimization of horizontal well with multiple frac design: number of ports, proppant weight**

As of 2016 – large scale implementation of horizontal holes with multi frac increased stages

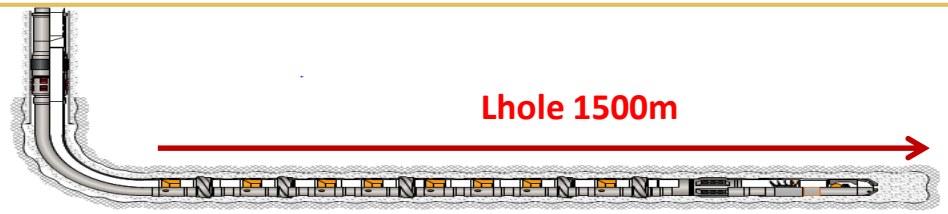


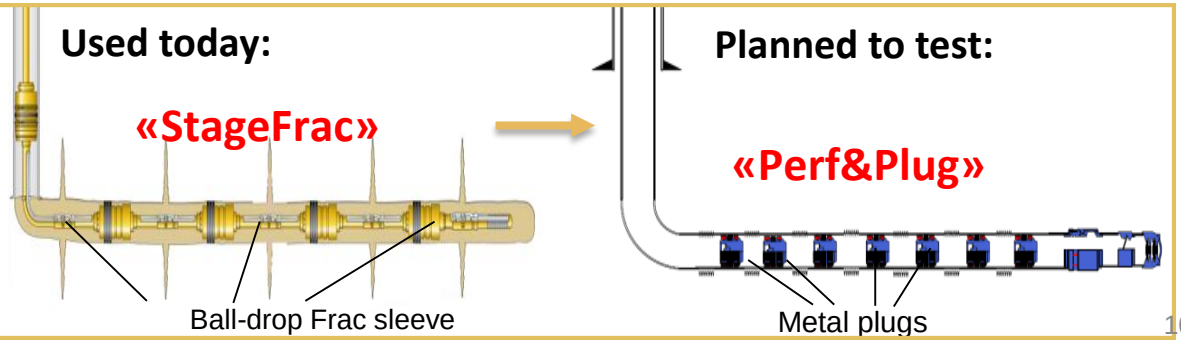

**2. Extension of horizontal section**

**HS multi frac: from 1500m + 20-30 stages**

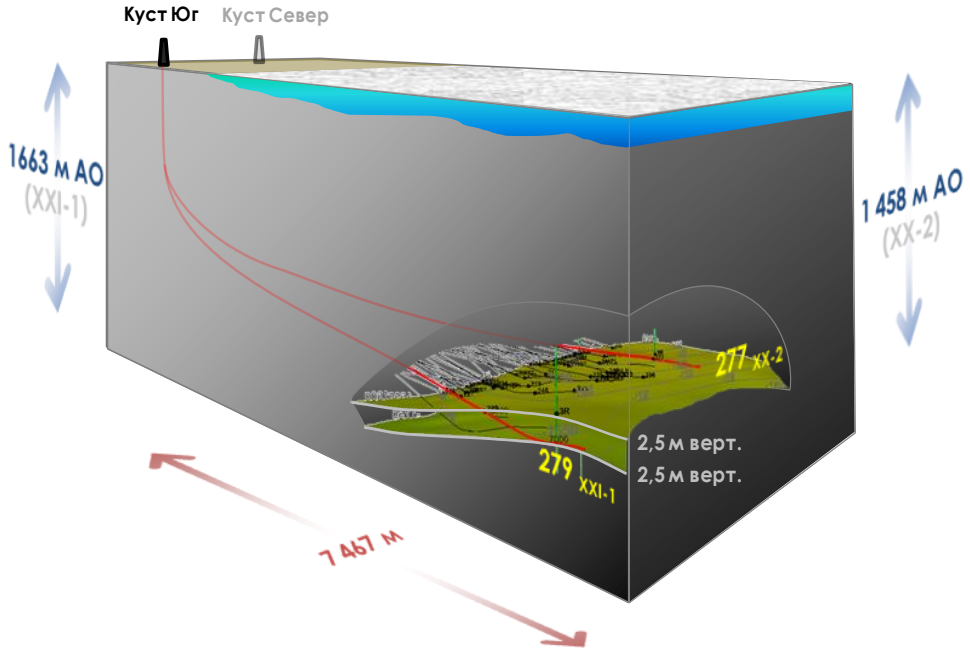


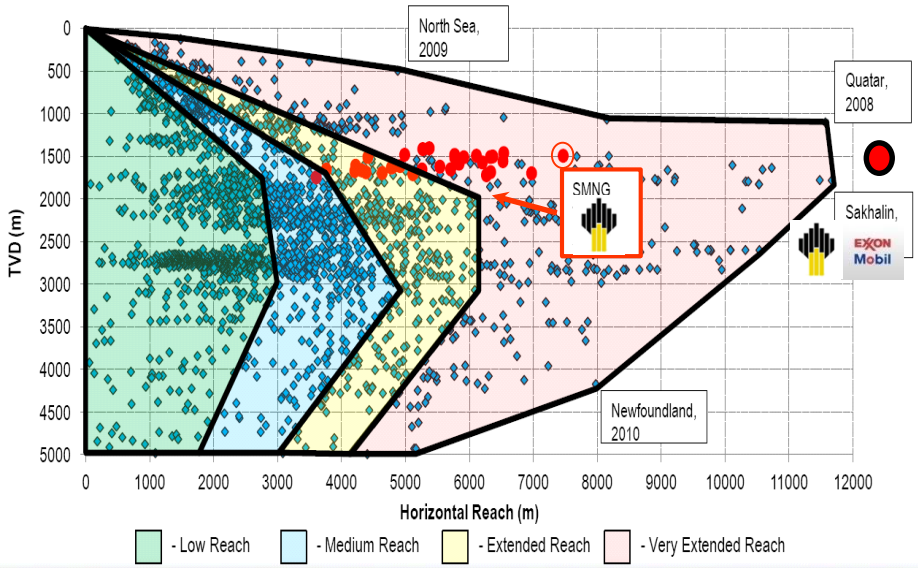

**3. Perf&Plug technology testing**

using internal flush liners (possibility for re-fracing and surveys without milling)



# ERD Wells

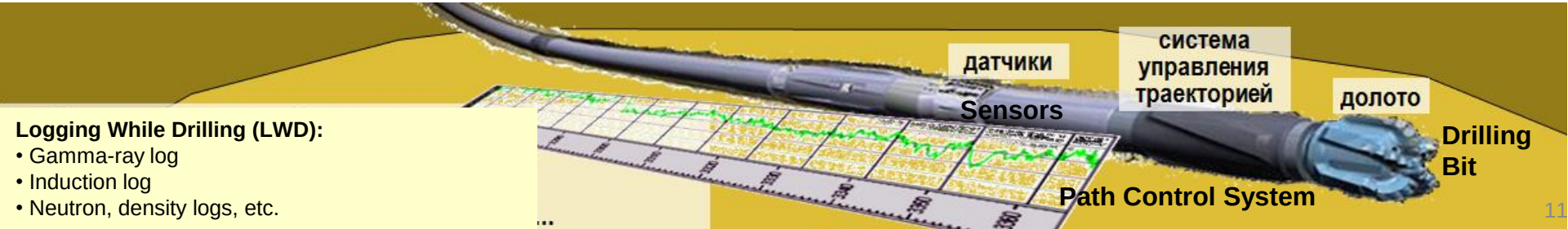



| | Well 1: | Well 2 |
|---|---|---|
| MD | 7 600m | 8119m |
| Lhor | 655m | 849m |
| NTG | 81% | 95% |
| Qoil | 437 t/day | 260 t/day |

## Results:

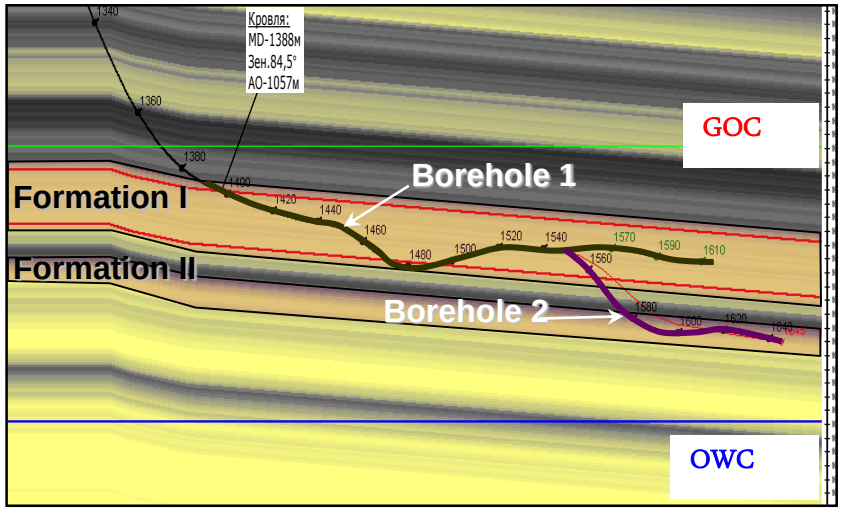
- MD world record 13,500m
- CAPEX reduction (decline from platforms)
- Economically viable project
- ERD Wells in 2-3m reservoir

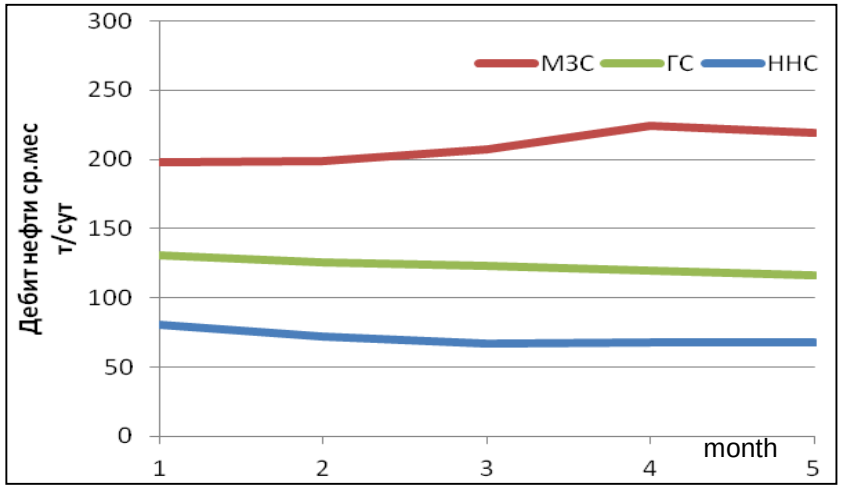



**Logging While Drilling (LWD):**
- Gamma-ray log
- Induction log
- Neutron, density logs, etc.

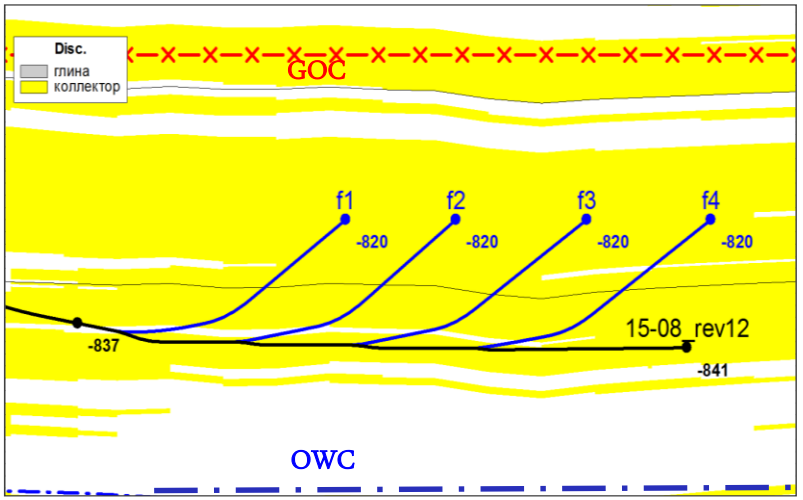
# Multilateral wells – EOR solution in oil rim zones and dissected crossection

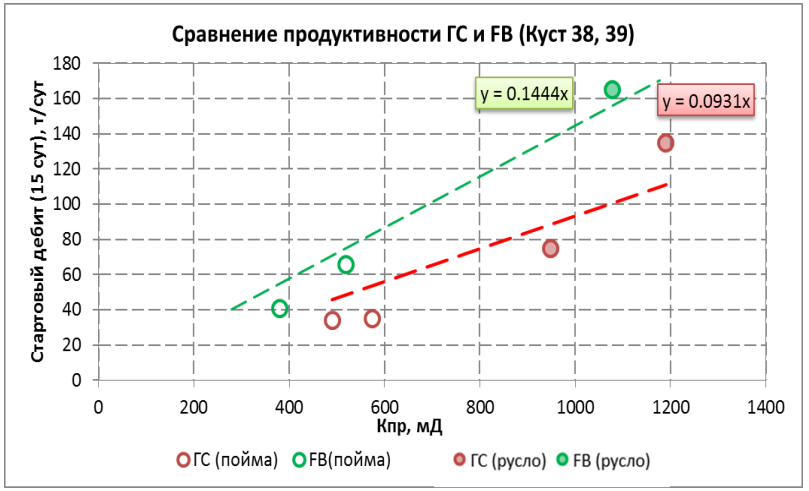
Carbonate reservoir




Terrigenous reservoir



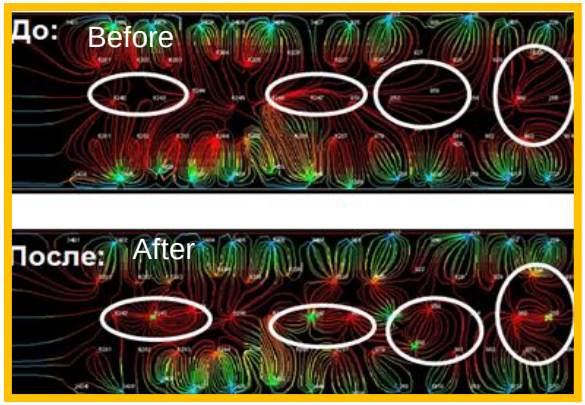

## Results:

Productivity increase of Multilateral well is by **35-50%** higher than horizontal

Effective approach towards development of highly dissected and carbonate reservoirs

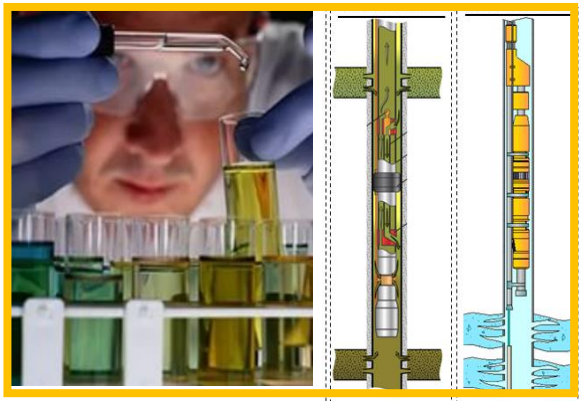
# Efficiency improvement of complex brownfield development

# Examples of solutions to improve brownfields development efficiency




**RESERVOIR FLOODING OPTIMIZATION**

- Systematic approach towards water flooding analysis
- Filtration flows management, grid transformation
- Compensatory measures to improve formation energy
- Ineffective injection decrease
- Integrated effect on formation (action from injection and producing wells)



**PHYSICAL AND CHEMICAL METHODS, PROFILE ALIGNMENT**

- Physical and chemical methods in the near-wellbore area (non-sludging, cross linked polymers)
- Dual production/injection
- Squeeze-cementing
- Further perforation/ reperforation with low drainage (by thickness)
- EOR technology (tertiary) – injection of gas, water-gas, thermo polymers

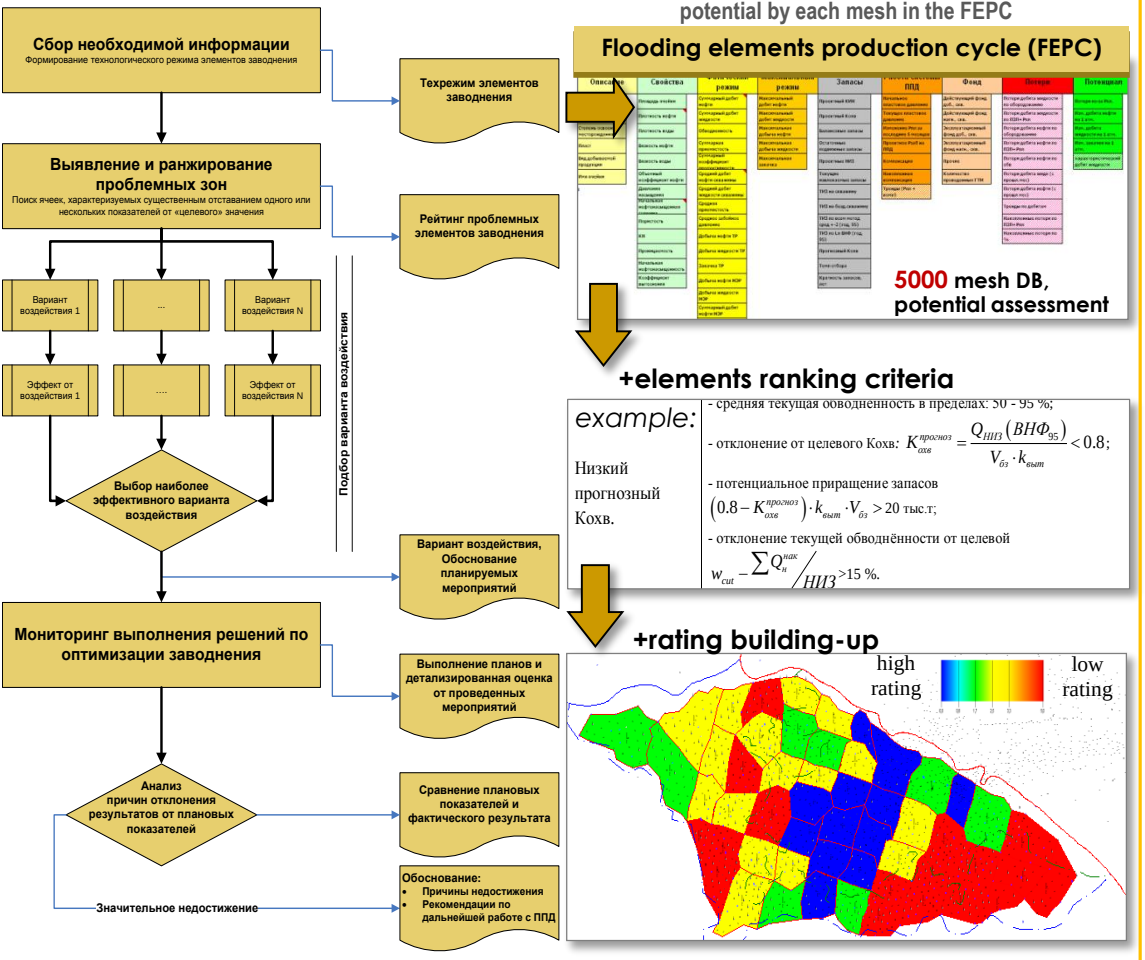
**SIDETRACKS, WELL STOCK RECOVERY**

- Sidetrack with deviation into low-drainage zones (by the area)
- Wasteless sidetracking (well recovery)
- Horizontal sidetracking
- Well reactivation

# Integrated approach towards water flooding management for EOR purposes

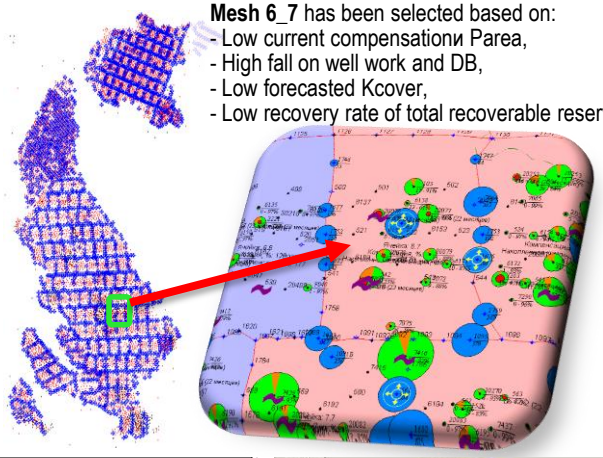
## Water flooding block analysis

Автоматическое формирование, ранжирование и первичная оценка потенциала по каждой сетке в ГФЭК

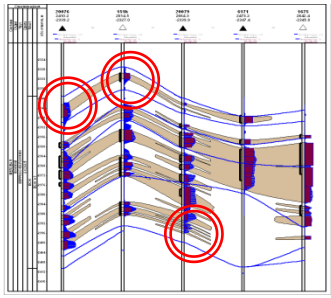



**Focus on the mesh ranked as the most problematic in terms of development and maximum possible potential**

## Example of an integrated approach on brownfield mesh



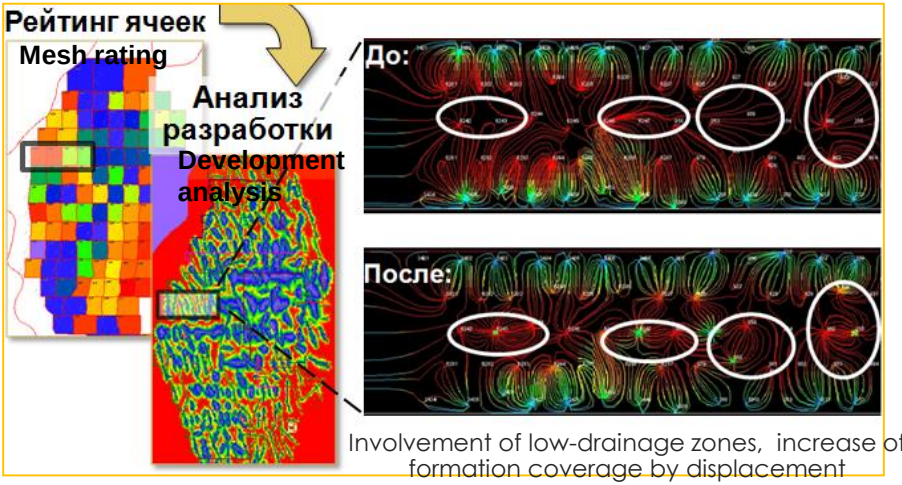
**Mesh 6_7** has been selected based on:
- Low current compensationи Parea,
- High fall on well work and DB,
- Low forecasted Kcover,
- Low recovery rate of total recoverable reserves.




| Types of activities | Effect | Detailed breakdown |
|---|---|---|
| To increase Кохв (Kcover) | + 74 т/day | - Sidetrack with ВБД - 1 well;<br>- Re-perforation- 2 wells;<br>- Squeeze cementing - 1 скв;<br>- Refrac - 1 well;<br>- EOR- 2 wells; |
| To increase the recovery rate | + 21 /day | - BHT- 1 well;<br>- Production stimulation - 1 well; |
| Compensation activities for reservoir pressure maintenance | | - BHT during RPM - 4 wells;<br>- Re-perforation- 2 wells;<br>- as well as 2 logs and 1 dynamic well test |
| Result | +95 t/day(+30 %)<br>+3% to ORF | The work is successful |

# Water flooding technology: results

## Water flooding mesh rating and integrated effect on the formation




Involvement of low-drainage zones, increase of formation coverage by displacement

## Example of an integrated approach in brownfield

(foil field in general)


## WATER FLOODING OPTIMIZATION:

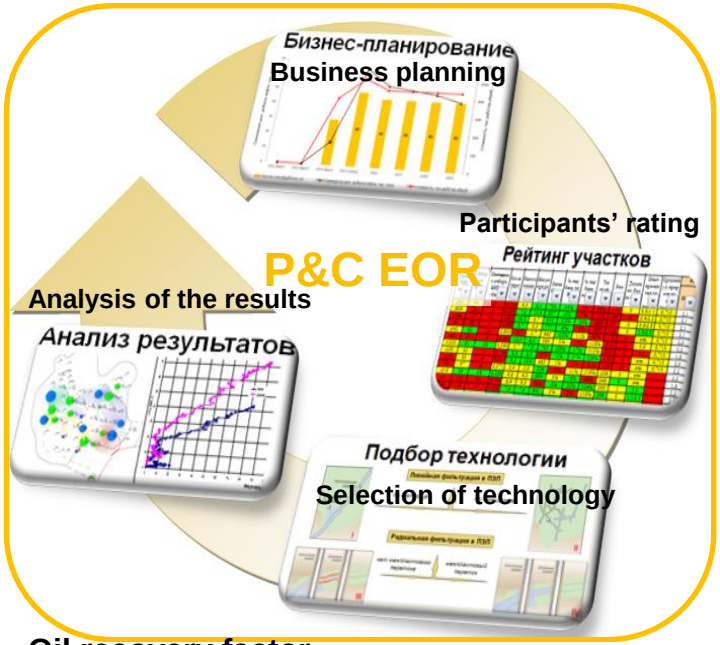
- State-of-the-art IT technologies for monitoring and simulation in the scope of the field development
- Systematic approach towards water flooding analysis and point focusing on problem (potential) mesh
- Using state-of-the-art technology (dual injection, physical and chemical EOR, hydraulic fracturing, new completion systems, etc.)
- Timeliness and extensive coverage of the well stock by reservoir pressure maintenance activities

# Physical and chemical EOR

## Physical & Chemical EOR and EOR projects by regions

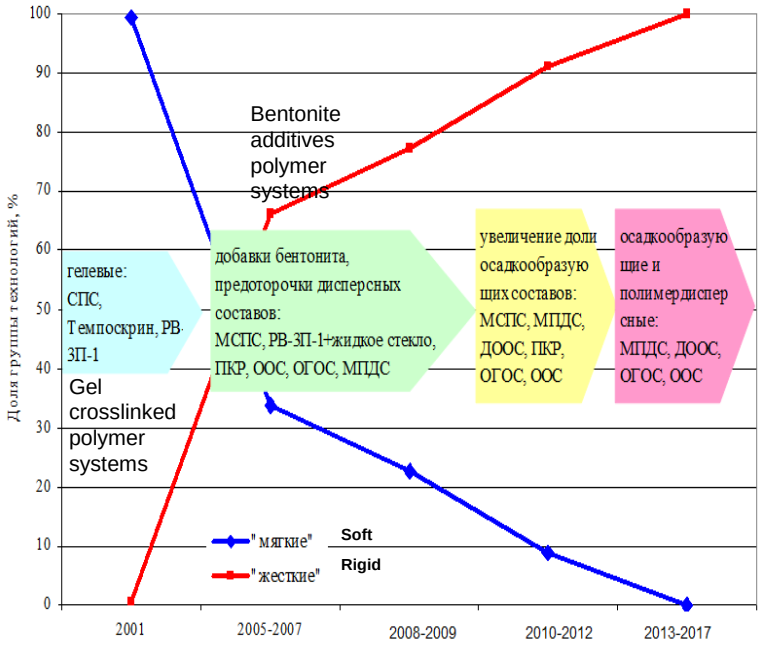

Дочерние предприятия РН в разных регионах России

**As of 2012 number of physical and chemical EOR has increased by 30%.**
**In 2016 ~400 well operations performed**




# Physical and chemical enhanced oil recovery (EOR) methods
# Evolution of solutions on the example of YuganskNeftegaz

**P&C EOR technology movement**




**Evolution of approaches towards P&C EOR in the fields of RN-YNG**

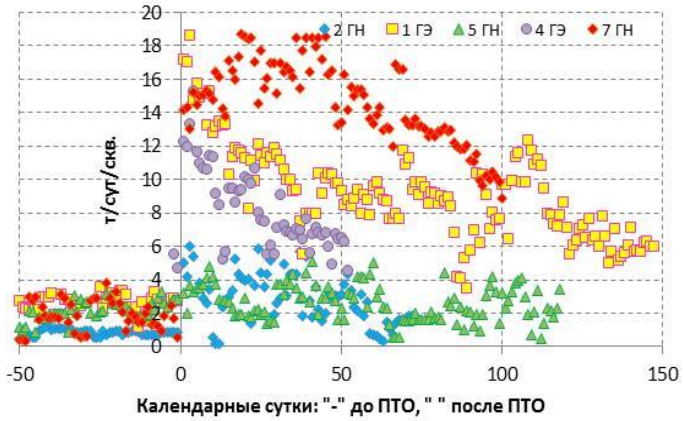
| | | |
|---|---|---|
| **1990-ies Early 2000-ies** | - high water cut | **Operation at ~15 fields** with high degree of maturity.<br>Basic volume: monolithic Cretaceous deposits at the late stage.<br>Low effectiveness of the operation. |
| **2005-2007** | - high water cut;<br>- heterogeneity; | **Operation at 10-12 fields** with high degree of maturity.<br>Performed R&D to summarize the world experience, development of the technology utilization matrix, gels design engineering. |
| **2008-2012** | - high and advanced water cut;<br>- heterogeneity/ compartmentalization;<br>- lagging in recovery of reserves;<br>- reserve on the dynamic level; | **Reduced to 8 fields** – applying the approach: "focus on successful fields, prohibition on unsuccessful fields" .<br>The "rigid" EOR methods testing.<br>EOR increase in hard-to-recover (HTR) reserves and heterogeneous up to 70%,<br>Failure in the monolithic Cretaceous deposits with high water cut. |
| **2013-2017** | - high and advanced water cut;<br>- heterogeneity/ compartmentalization;<br>- lagging in recovery of reserves;<br>- reserve on the dynamic level;<br>- compensation>100-110%;<br>- absence of Parea drop;<br>- Fluid decline rate < 1-2% per year;<br>- Water cut decline rate > 10% per year;<br>- Economic criteria (spec. eff. >= Frac) | EOR focus **on the 5 basic locations** with high efficiency based on past years experience. Share in HTR > 80%.<br>For wells with dual injection – injection of P&C EOR **through dual injection assemblies** with choke restriction and decrease the injection pressure all along the flushed out formation.<br>Using the trace surveys to identify water cut routes, calculation of volumes and to design location of the rigid backfilling compound in fractures. |

## Key further directions of P&C EOR:

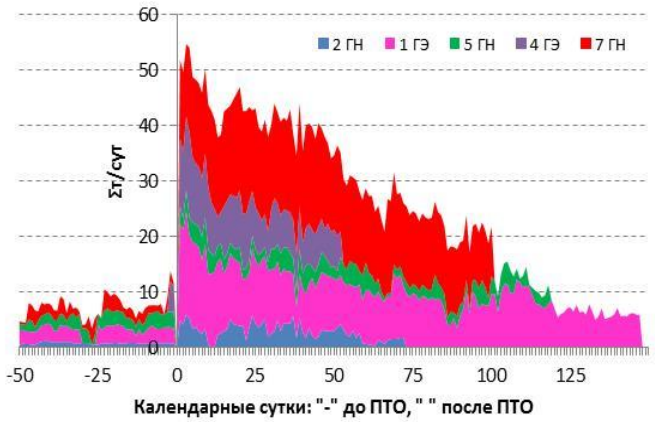
- **Performance evaluation methodology and automation of calculations in RN-KIN software**
- **Focus on the most effective fields and areas**
- **Reduction of the "soft/non-damaging" technologies, increase of the "rigid" ones** (in low-permeable reservoirs to control the frac propagation and for autoFrac purposes);
- **Mesh rating improvement to plan P&C EOR activities**
- **New technologies testing** (swellable polymers – thermo gels; relative permeability modificators, ASP water flooding, etc.)

# Sakhalin: experience of using thermal EOR for high-viscosity oil at the late development stage

**Combined oil flow rates of horizontal wells after the P&T activities**




**Total oil flow rate of horizontal wells after the P&T activities**



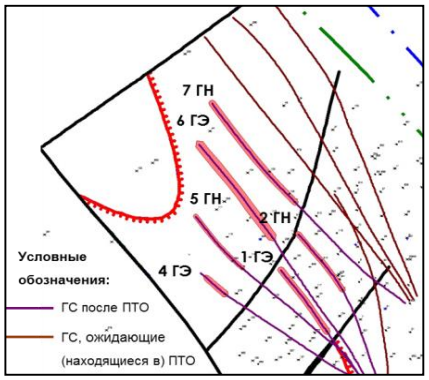

**Mean oil flow rate growth multiplication factor - 3,8 units**

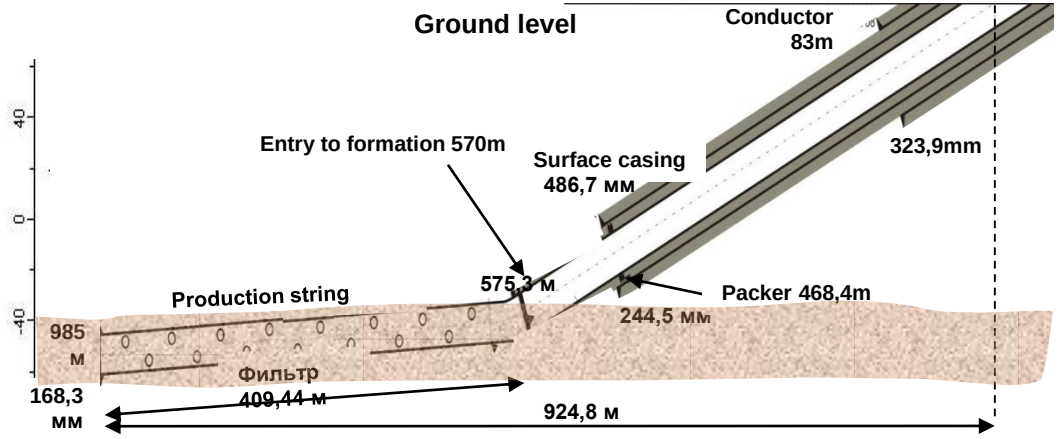
**Due to TM ORF has increased by 1,4 times**

**Details on P&T activities performed**

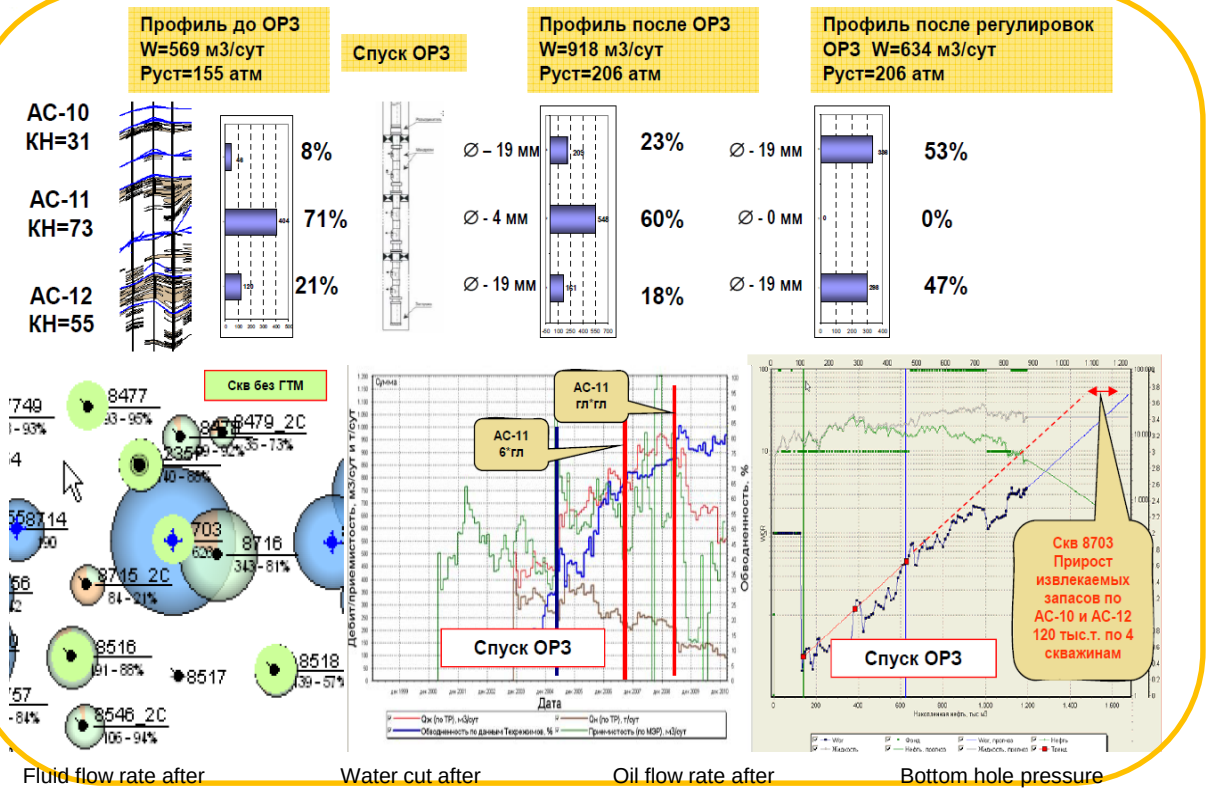
| Well | Well 1 | Well 2 | Well 3 | Well 4 | Well 5 |
|---|---|---|---|---|---|
| Well length by formation, m | 212 | 174 | 212 | 73 | 401 |
| Footage by reservoir, m | 197 | 141 | 194 | 68 | 265 |
| Duration of P&T activity, days | 41 | 42 | 37 | 45 | 122 |
| Accumulated steam injection, t | 12457 | 15387 | 9628 | 8213 | 27867 |
| Pump over zone radius by the cylinder, m | 8,0 | 10,2 | 6,6 | 10,5 | 9,6 |
| Mean stem temperature during P&T, °C | 198 | 174 | 166 | 185 | 204 |
| Flow rate prior to stoppage for P&T, t/day | 0,8 | 2,7 | 2,4 | 5,2 | 2,0 |
| Flow rate after P&T, t/day | 3,1 | 11,3 | 3,0 | 12,0 | 14,5 |
| Flow rate multiplication factor, unit | 3,9 | 4,2 | 1,3 | 2,3 | 7,3 |
| Duration of the effect, days (months) | 124 (4,1) | 206 (6,8) | 84 (2,8) | 74 (2,4) | 119 (3,9) |

High-viscosity oil (**350 cP**), %B = **96**%



# Dual injection.
# Example of optimization approach

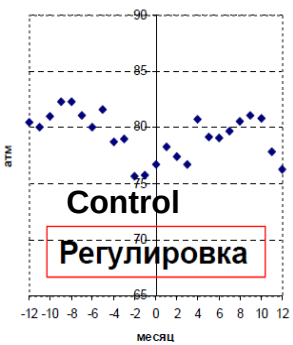



Fluid flow rate after dual injection


Water cut after dual injection


Oil flow rate after dual injection


Bottom hole pressure after dual injection




## Implementation of dual injection allows to:

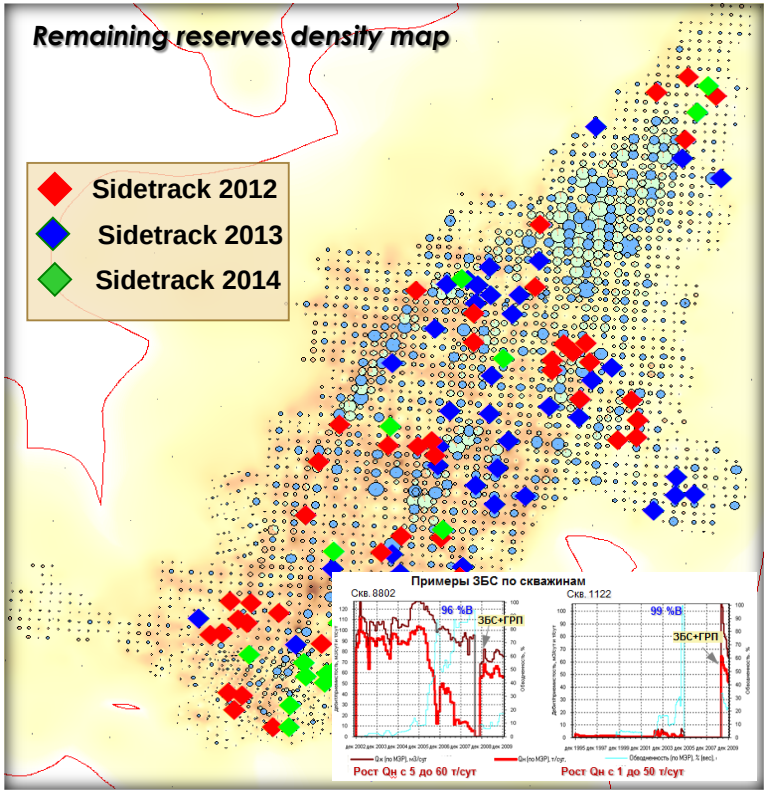
1. Improve oil recovery due to additional involvement of light-size secondary layers;

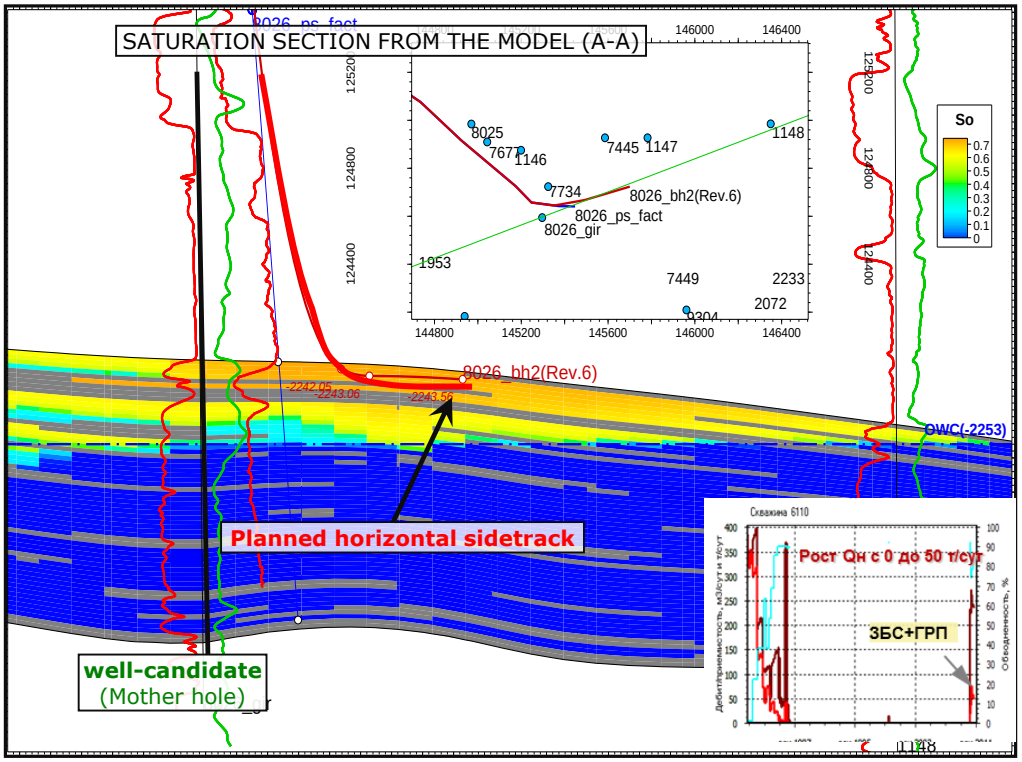
2. Reduce Capex on drilling and reservoir-pressure maintenance for additional wells;

3. Carry our real-time control of formation pressure, direction and speed of formation fluid filtration

# Sidetracking as EOR method

## Conventional sidetracks and horizontal sidetracks in drilled out areas




**Since 2012 the number of sidetracks/horizontal sidetracks in Rosneft has increased by a factor of 3+**
**In 2016 the number of operations exceeded 1000.**

## Factors of an effective sidetrack

- Qualitative localization of total recoverable reserves, their estimate
- Quantitative evaluation of productivity and water content
- Path design and feasibility study
- Applied borehole completion technology and fracing techniques
- High-quality development

# Conclusions

1) A systematic enhanced oil recovery process is implemented in Rosneft for various geological settings
2) EOR activities planning methodology is realized in Rosneft software packages utilizing in-house techniques and standards
3) Rosneft implements a wide range of EOR technologies both for greenfields and brownfields
4) Special attention is paid to EOR in low-permeable and formations with complex features. For the past several years the volumes of horizontal drilling with multistage frac and multilaterals have significantly increased.
5) More than 95% of Rosneft's production is carried out using water flooding, which makes it important for having systematic approaches towards reservoir pressure maintenance and the coverage increase by displacement
6) Rosneft has realized the process of utilizing physical and chemical EOR technology, that includes technology test for various reservoir properties in its in-house labs prior to subsequent large-scale deployment
7) For enhanced oil recovery purposes the sidetracking volumes have been significantly increased in brownfields in the low-drainage formation sections
8) The system in place allows to improve field development efficiency at the late stage and in greenfields with complex geology due to application of the state-of-the-art technology.