SPE DISTINGUISHED LECTURER

Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

The Society is grateful to those companies that allow their professionals to serve as lecturers

Additional support provided by AIME

SPE International

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

The Unfulfilled Expectation of Horizontal Wells with Multi Stage Fracture Completions in Conventional Reservoirs - A Solution.

Krešo Kurt Butula

Director Schlumberger Moscow Research

Schlumberger

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

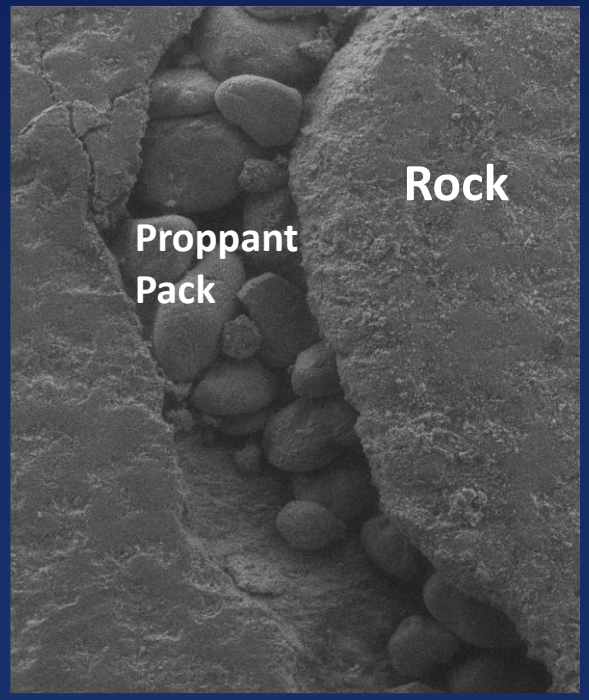
Outline

- Horizontal wells completed with multi stage fractures in conventional reservoirs
  - Conditions and concerns in waterflood
  - Failing expectations
- Possible solutions:
  - New wells - completion type and field development patterns
  - Old wells - re-fracturing horizontal wells with multi stage fracs
- Examples of pilot projects
- Conclusions and recommendations and main take-away

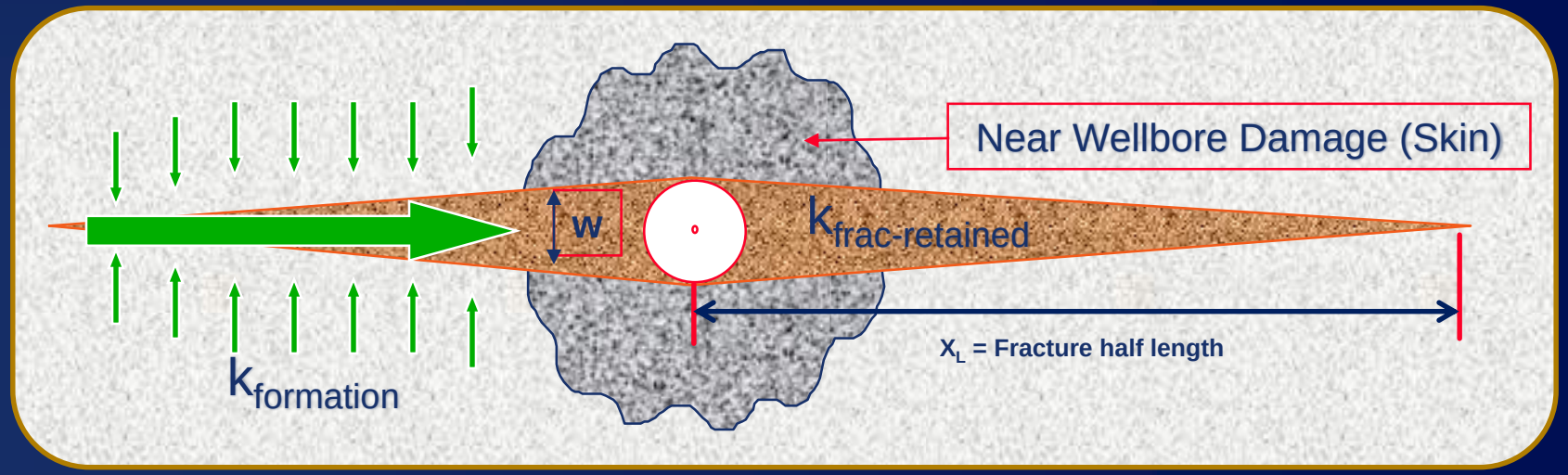
First: What is Hydraulic Fracturing…and What is Important

SPE DISTINGUISHED LECTURER

- **OPERATORS only interest: CONDUCTIVITY**
  - Maintain a highly conductive path C_{fD} (compared to the reservoir permeability) to increase well productivity
  - *Process: Injecting fluid (and proppant) into the formation above fracture pressure to create a crack in the rock…and keep it open*



$$C_{fD} = \frac{\text{Frac Conductivity}}{\text{Formation Deliverability}} = \frac{W \times k_{frac\text{-}retained}}{X_L \times k_{formation}}$$

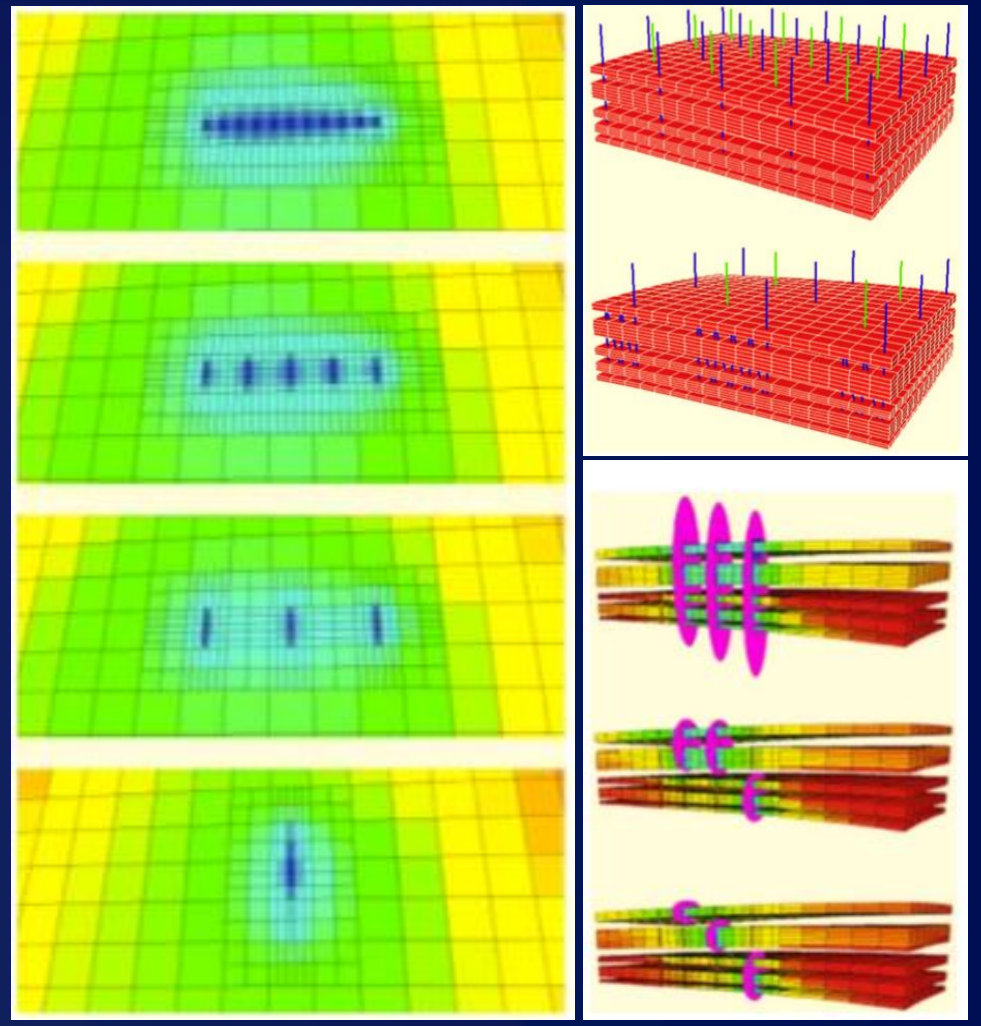


Warpinski, Sandia Labs. Nevada Test Site, Hydraulic Fracture Mineback

Why Horizontal Wells with Multi Stage Fracs (HWMSF) in conventional reservoirs?

SPE DISTINGUISHED LECTURER

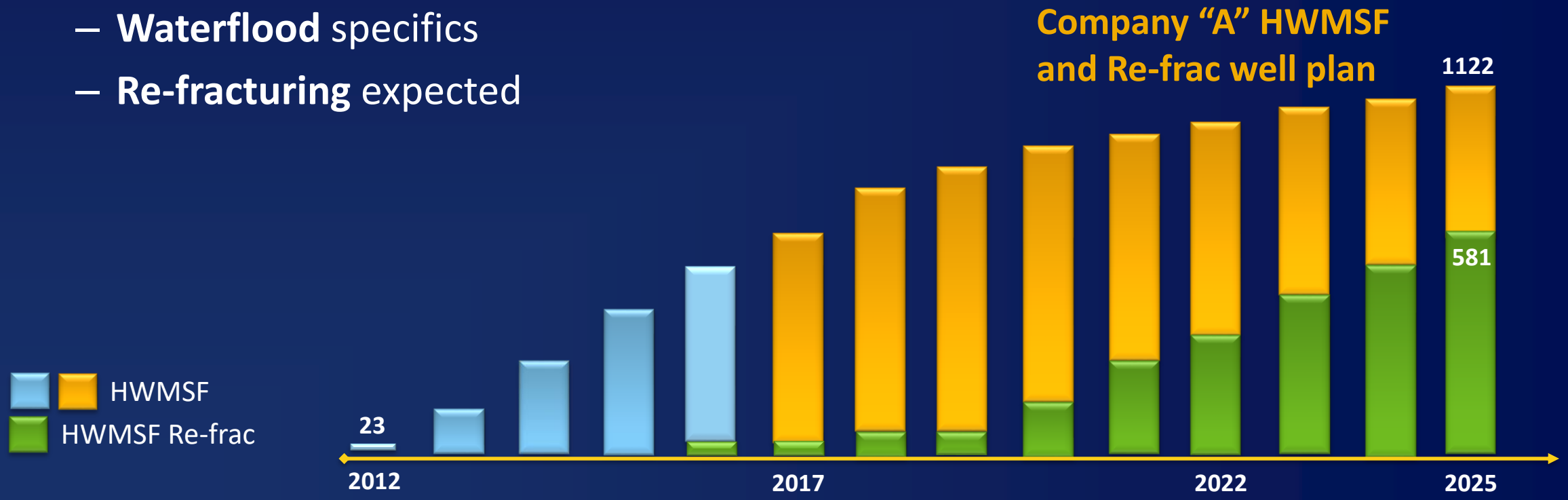
- Increase production
- Increase recovery
- Optimize economics
  - Surface infrastructure and wellbore construction CAPEX reduction
  - Lifting and water control OPEX reduction
  - Addressing less productive formations:
    - Low permeability, lateral and vertical anisotropy
- Environmental footprint
- Technology and competency
  - It just can be done!



Source: Butter M. et al SPE102633, 2006

HWMSF Market Example - Russia Case

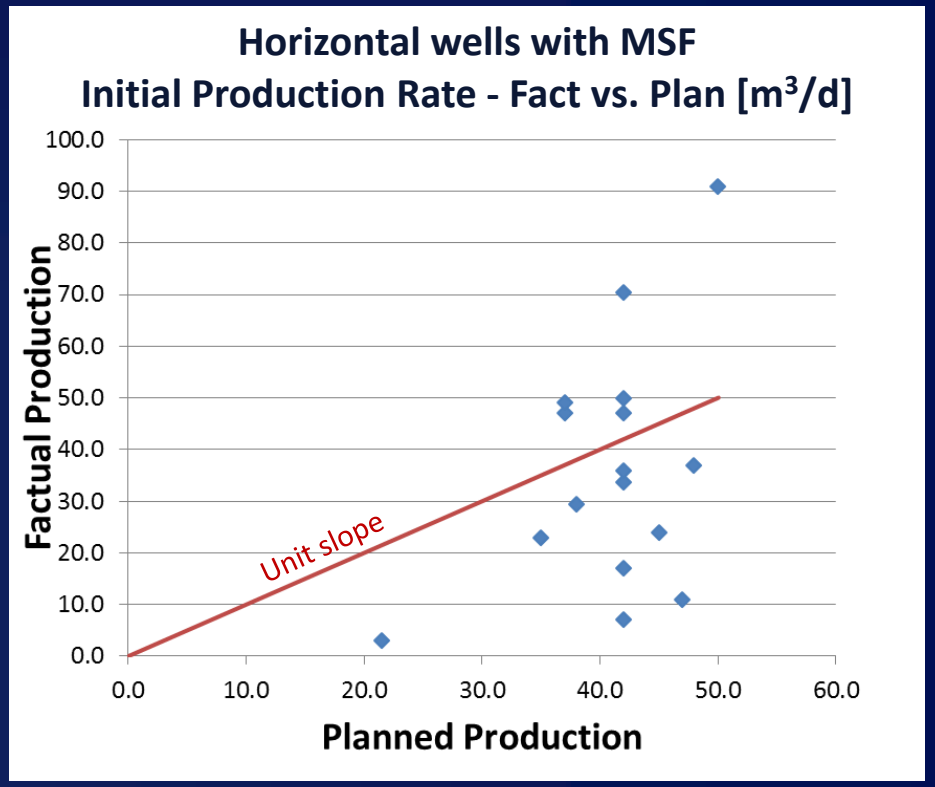
- The 2nd largest frac market specifics:
  - Maximizing **conductivity** and ceramic proppant
- HWMSF in **conventional reservoirs**
  - **Waterflood** specifics
  - **Re-fracturing** expected



Source: Ogorodov A. "Easy Frac Repeated Multistage Hydraulic Fracturing (MHF) in Horizontal Wells" SPE ATW Moscow , 2016

What are the issues with HWMSF?

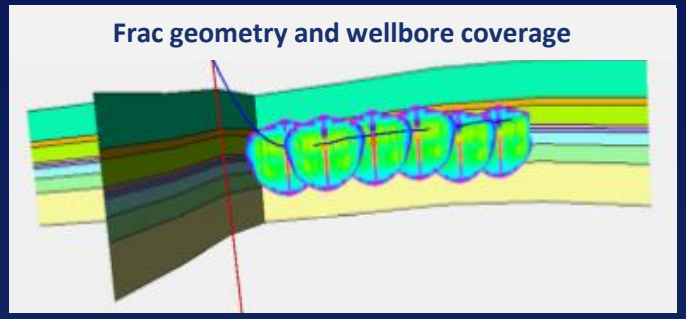
- Not reaching expected **initial production**
- Rapid **productivity decline**
- Rapid **water breakthrough**
  - Economically Viable?
- **Reasons:**
  - Frac and frac geometry
  - Geology
  - Workover
  - Well placement
  - …
  - **Pressure support and pattern**
  - **Completion type**



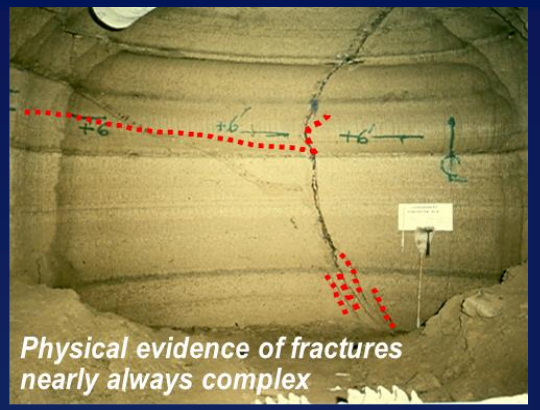
Source: Sommer F. at West Siberia Regional Technology Forum, 2012

Potential Fracture Failure Mechanisms

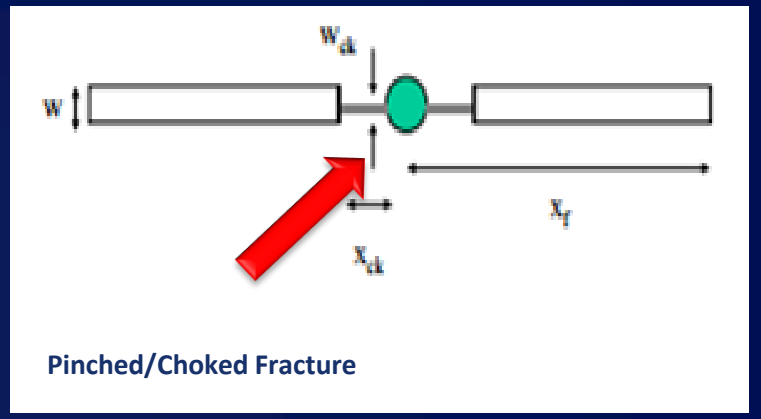
- Frac, frac geometry & connectivity
- Workover
- Reservoir
- Well placement
- …



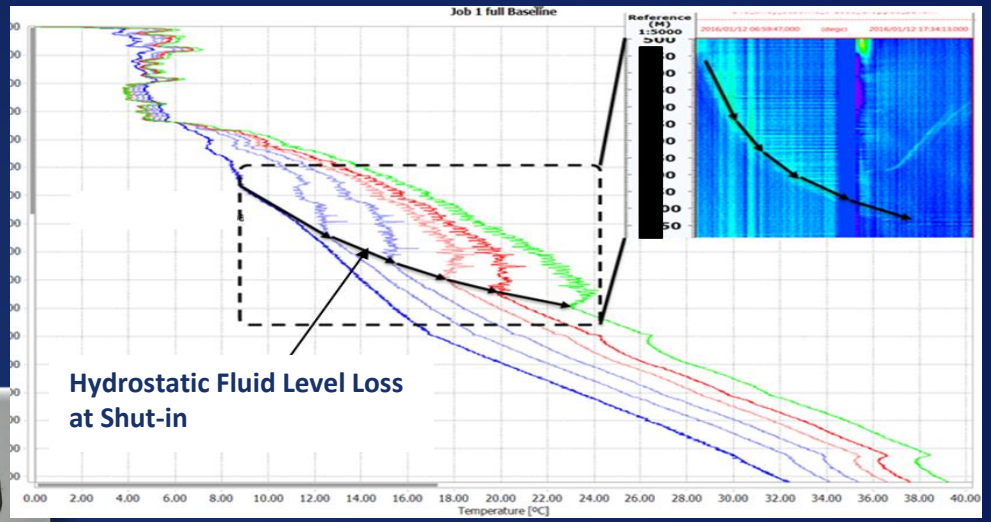
Source: S.Doktor SPE- 171221



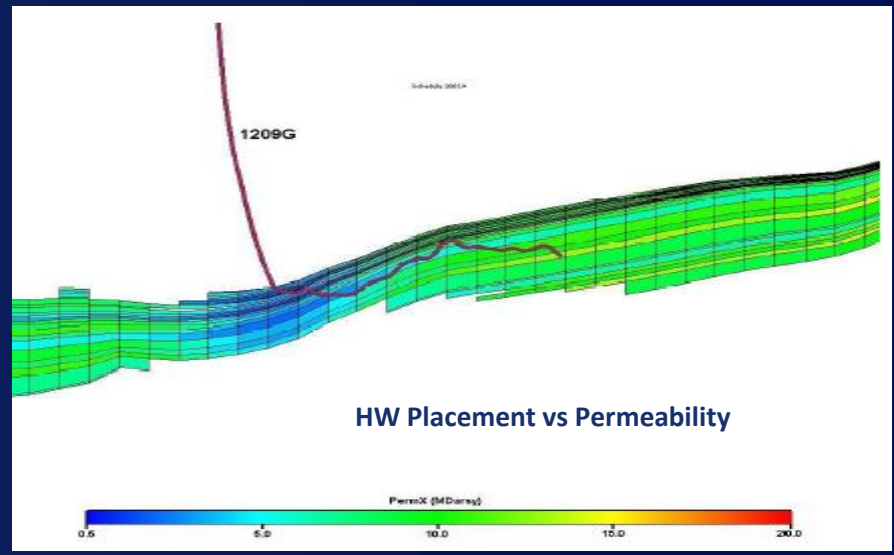
Source: Warpinski, Sandia Labs. Nevada Test Site, Hydraulic Fracture Mineback



Source: D.Romero SPE-73758



Source: Malanya G. et al. SPE-182086, 2016



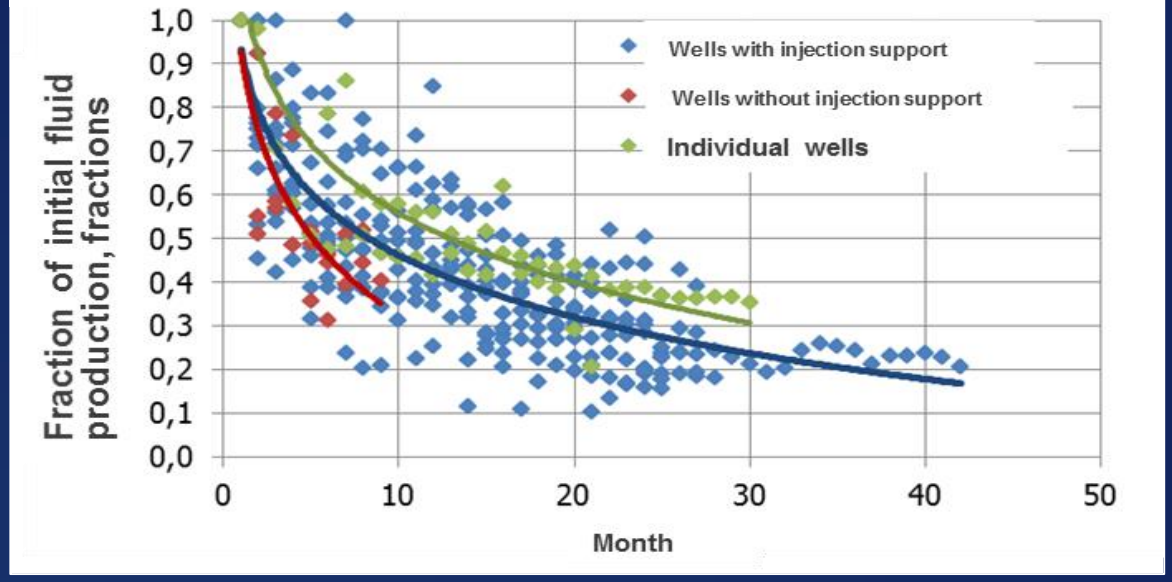
Source: A.Brovchuk SPE- 102417

HWMSF IN WATERFLOOD

Conventional Reservoirs Waterflood

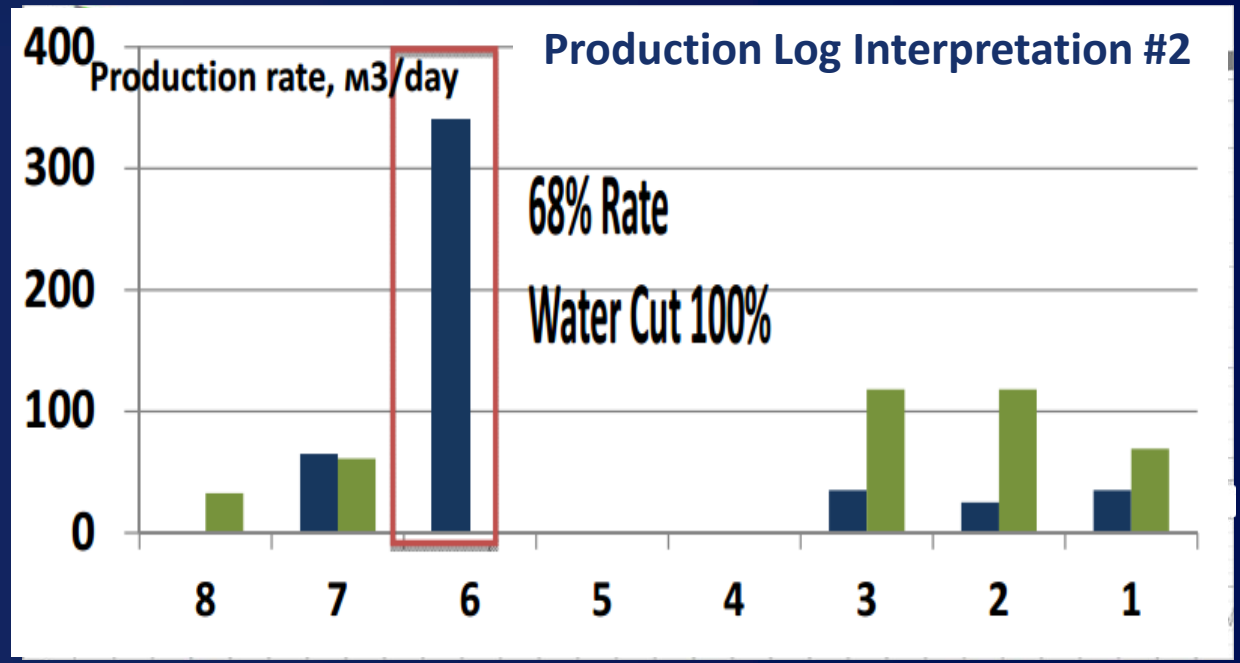
- **Maintain production**
  - **Reservoir pressure maintenance**
    - Maximize water injection
    - Above frac gradient / thermal effects
- **Injector/Producer**
  - **Water front movement & breakthrough**
    - Completion design / efficiency
    - Pattern design

Production Rate Ratio Depending on Water Injection



Source: Nemirovich G. "Horizontal drilling with multifracs – access to challenged reserves of Tyumen suite" SPE ATW Moscow, 2013

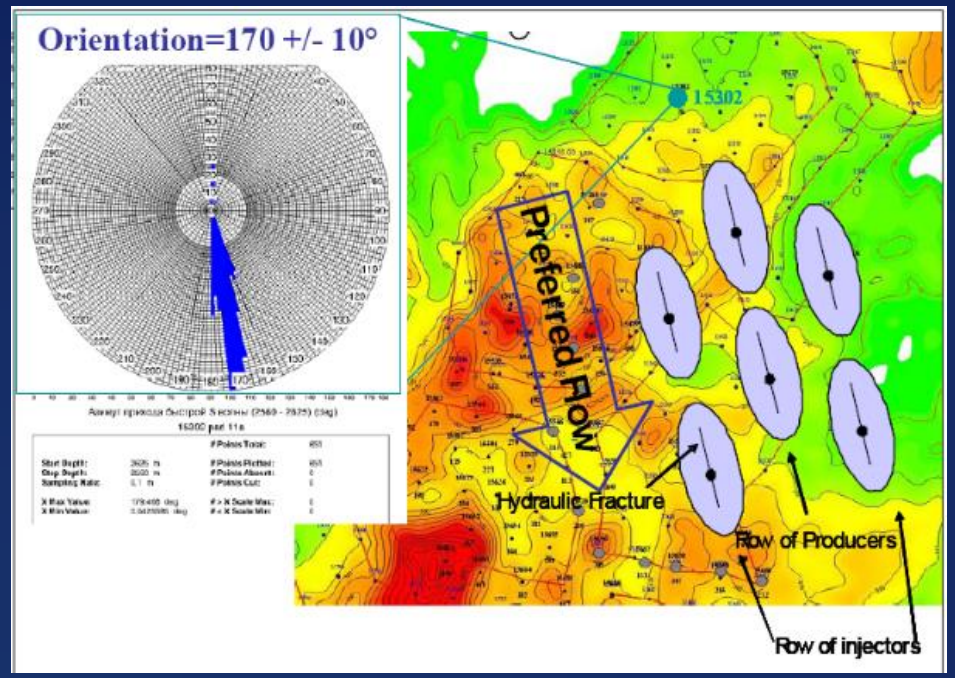
Production Log Interpretation #2



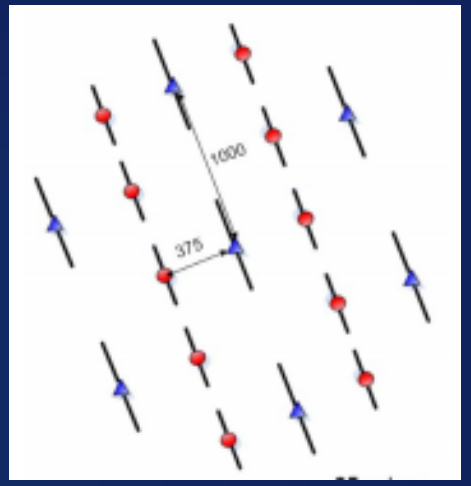
Source: Burdin K. et al SPE168288, 2014

Hydraulic Fracturing in Waterflood

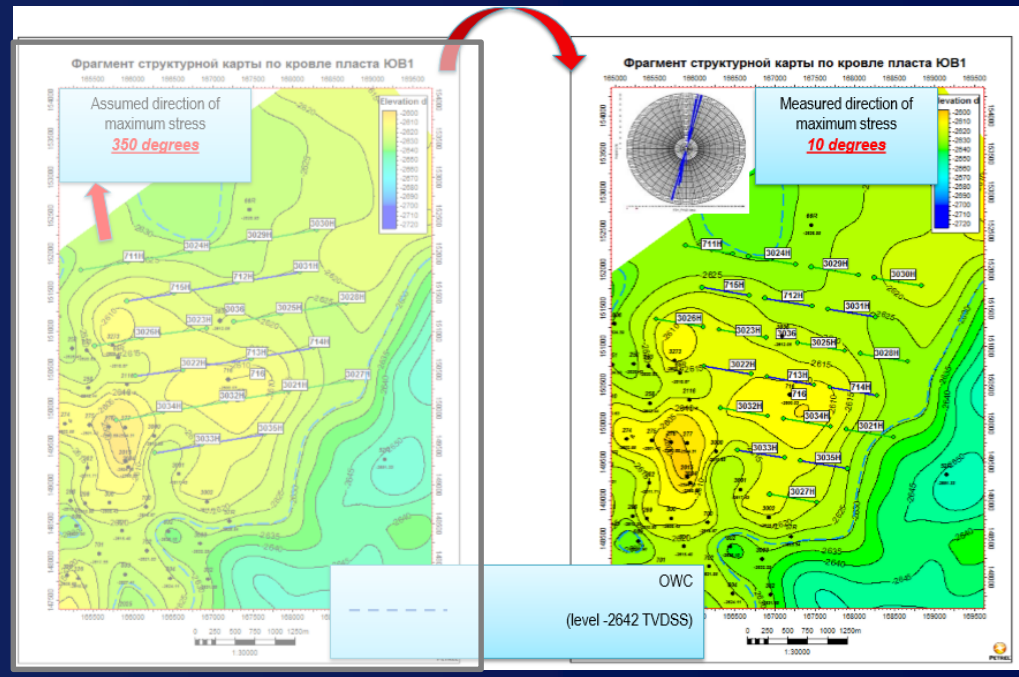
- Defining maximum horizontal stress **azimuthal orientation is critical**
  - Hydraulic fracture / horizontal wellbore orientation
  - Well placement/field development pattern (FDP)
    - Re-orientation of Injectors and Producers



Source: T. Krychkova et al. SPE103987



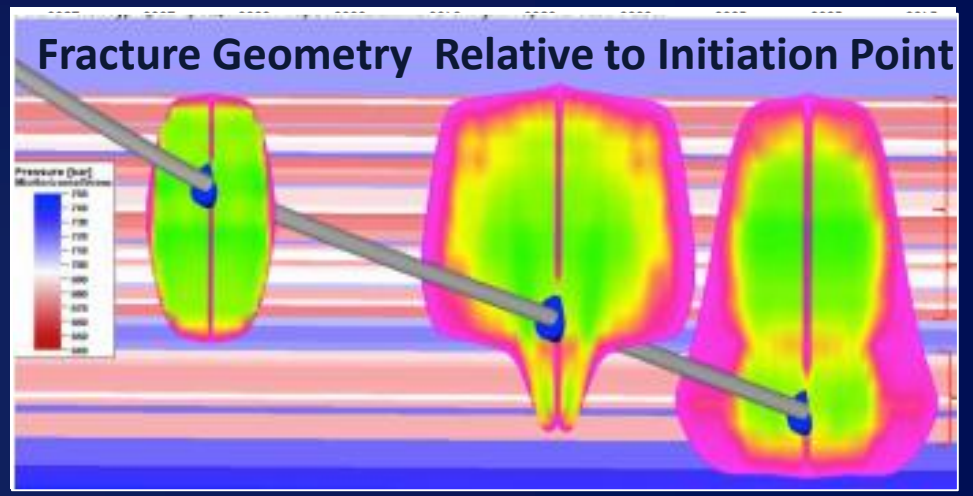
Source: Baikov V.et al. 2011



Source: Malyshev V. et al "Integrated approach for North-Khohryakovskoe field development with system of horizontal wells with multi-stage fracturing " SPE ATW Moscow, April 2013

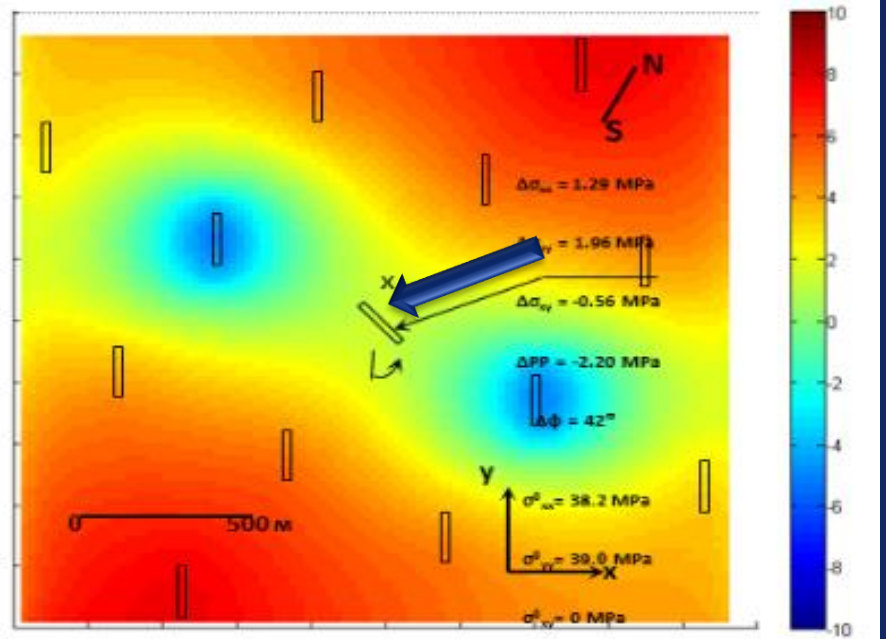
HWMSF Hydraulic Fracturing and Stresses

- Hydraulic frac **geometry and orientation** of frac/re-frac
  - Horizontal **stress isotropy/anisotropy**
  - **Pressure changes** from production and injection
  - Designed based on **4D Mechanical Earth Model**
  - Defined by completions type and design
  - Affected by recent frac placement



Source: Ablaev A. et al. SPE171277, 2014

Fracture Azimuthal Re-orientation

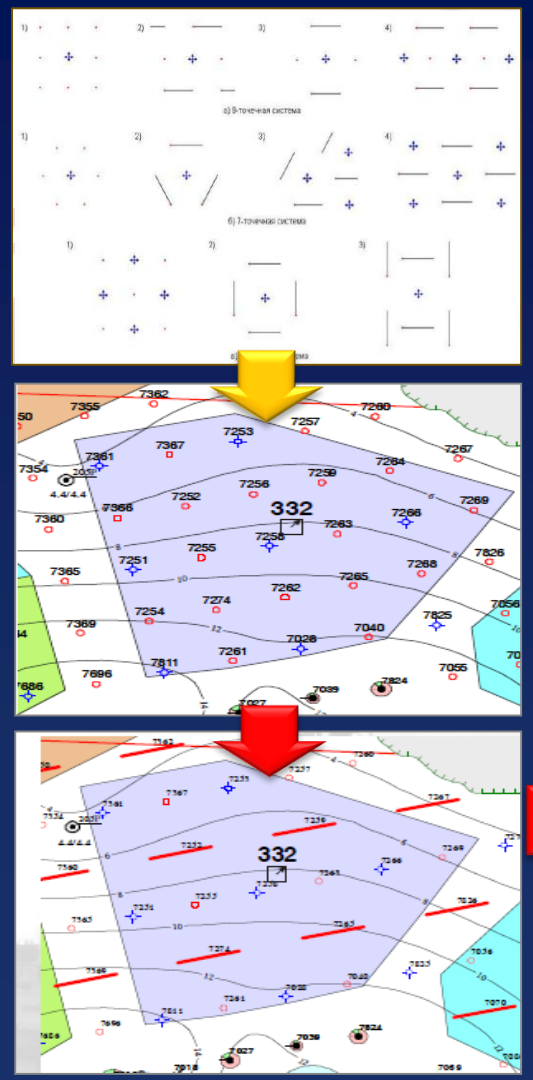


Source: Kuzmina et al. SPE 120749, 2009

- **Fracture initiation** along the horizontal wellbore
  - Designed based on **1D Mechanical Earth Model** (MEM)
  - Defined by completions type and design and wellbore placement

COMPLETION TYPE,
RESERVOIR PRESSURE SUPPORT AND FIELD DEVELOPMENT PATTERNS

HWMSF Common Design Patterns

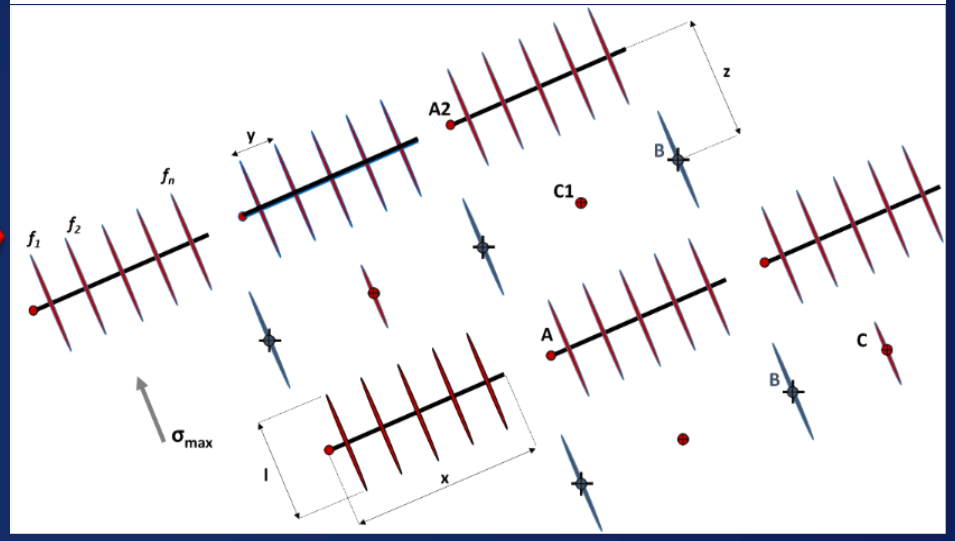


Source: Veremko, N.A. "Optimization formation production in Western Siberia using HW MSF" Lukoil SPE Moscow Section Presentation, 7th February,2012

Conventional low-perm reservoirs under waterflood:

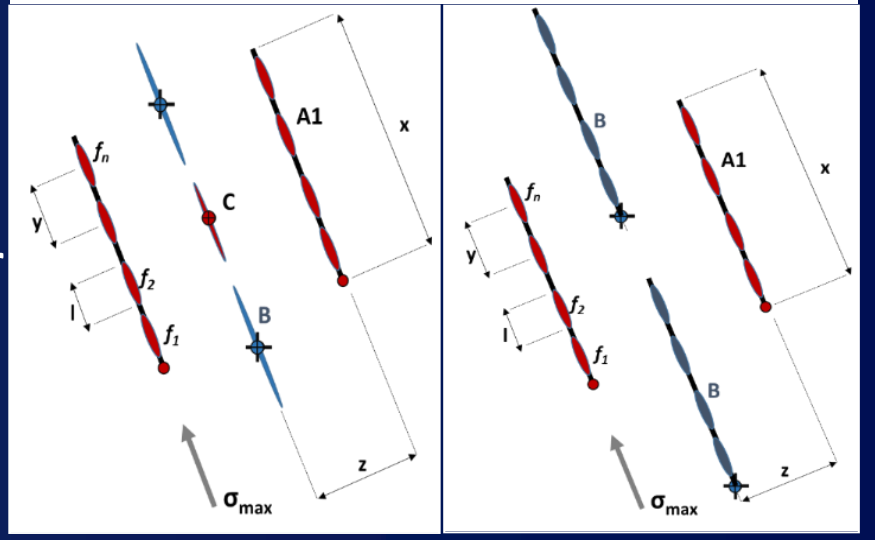
- Transition from fractured vertical well to HWMSF
  - Multitude of well design and pattern scenarios
    - Low permeability –> **Longer perpendicular hydraulic fractures**
    - Waterflood –> **Line drive**

Perpendicular fracs in HWMSF



or

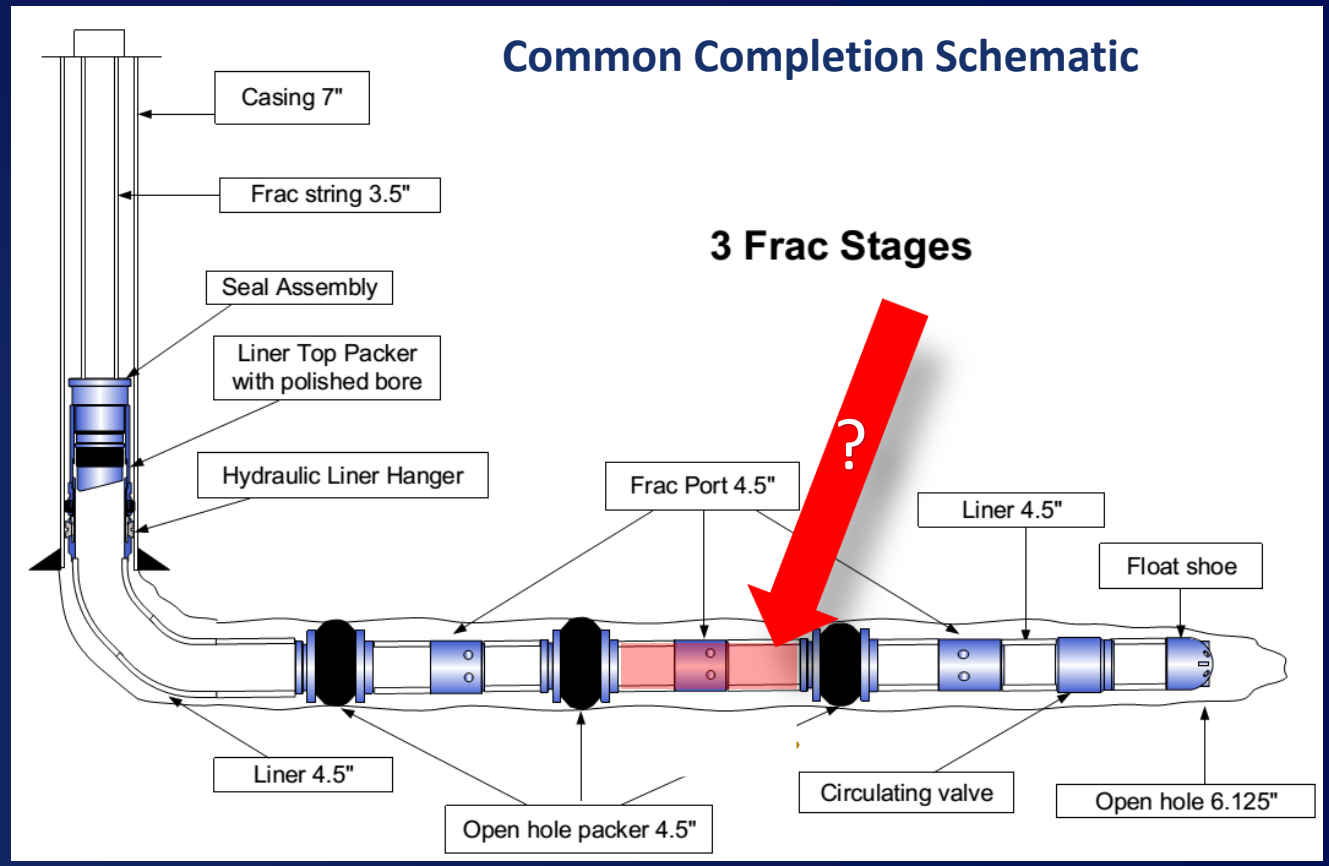
Longitudinal fracs in HWMSF



Source: Butula K.K. et al SPE181983, 2016

HWMSF Common Completion System

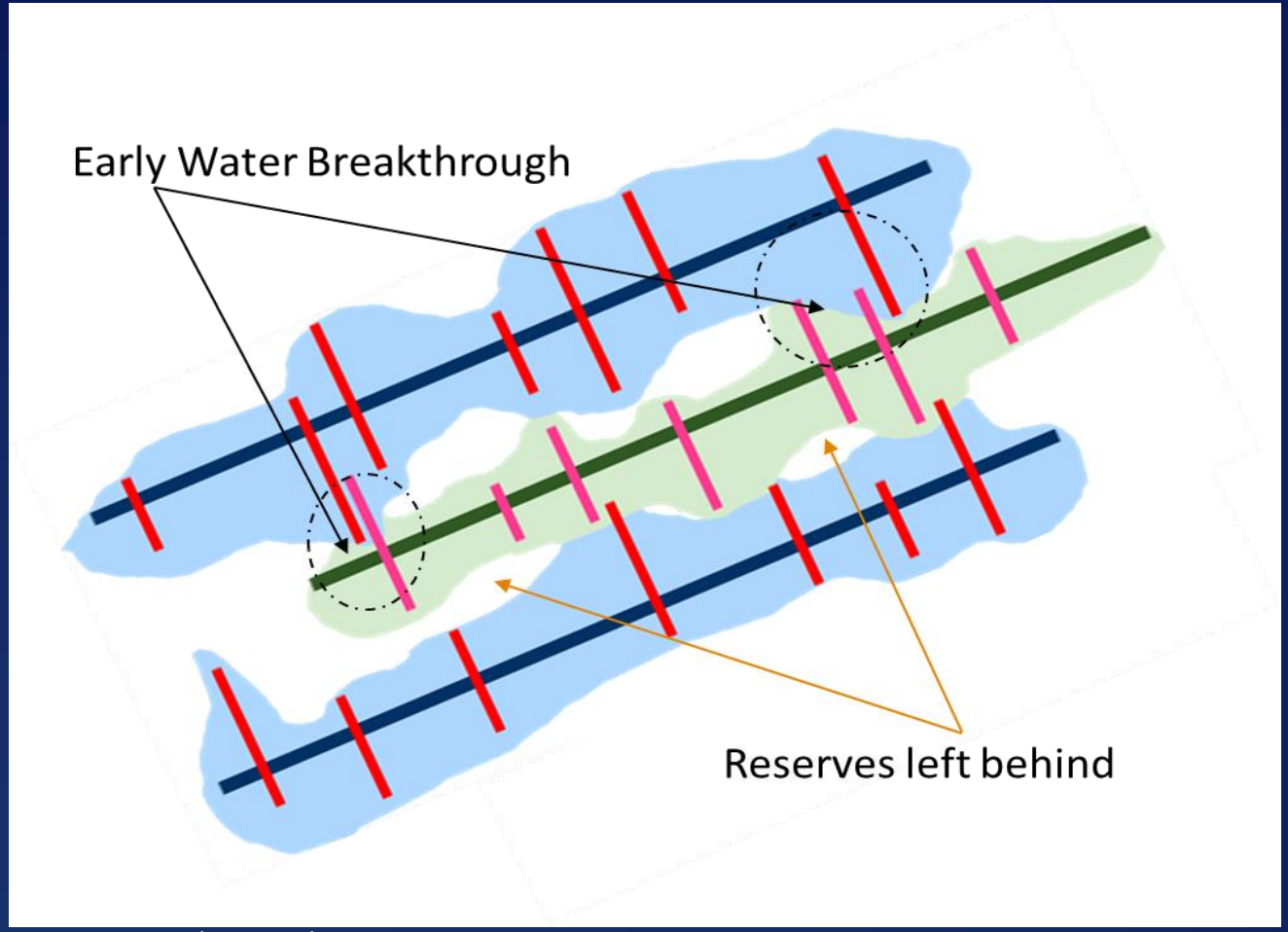
- **Open hole with ball drop frac ports** and **external packers**
  - Main benefits:
    - **No over-displacement**
    - Cost and simplicity
    - Sufficient ports and fracs
  - Limitations:
    - Production uncertainty
      - Frac positioning
      - Packer isolation
      - Water/Gas breakthrough control
    - Workover operations and interventions
- Other completions system tested



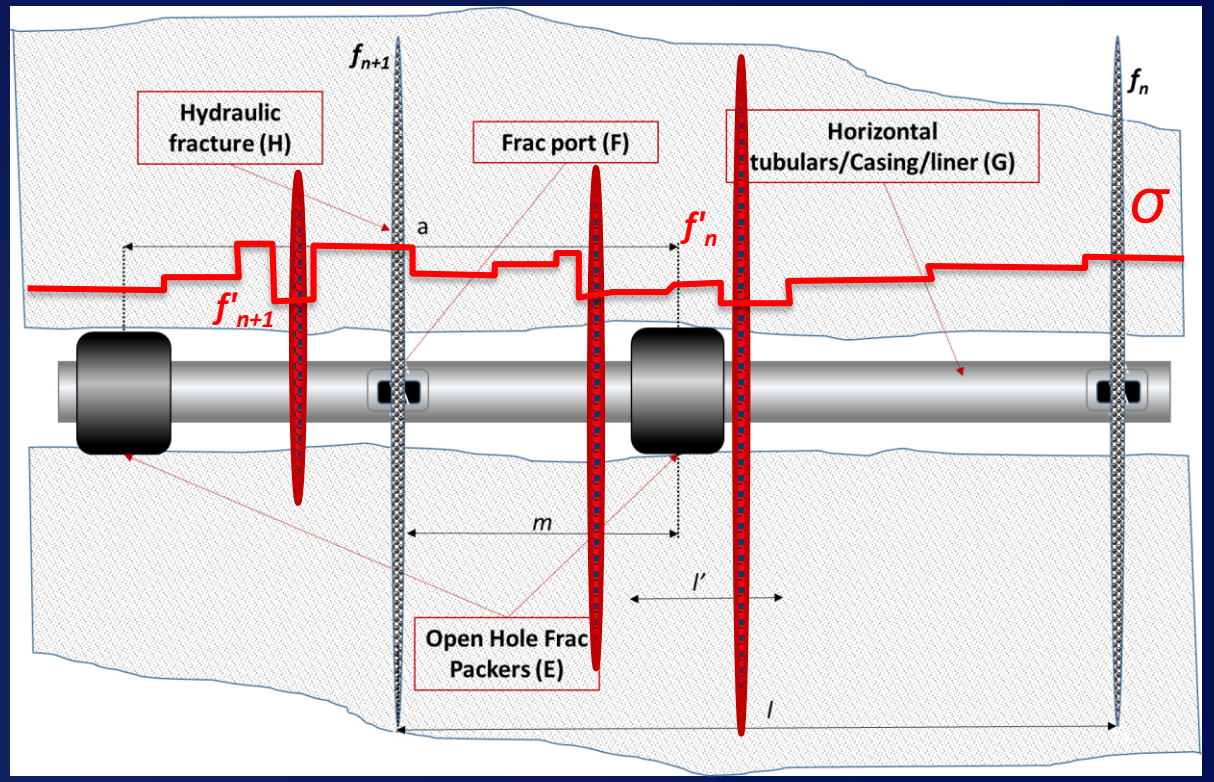
Source: Butula K.K. et al SPE176720, 2015

Common HWMSF: Poor Fracture Placement

- Multiple fractures occurrence
- Frac spacing different from designed



Source: Butula K.K. et al SPE181983, 2016



Source: Butula K.K. et al SPE181983, 2016

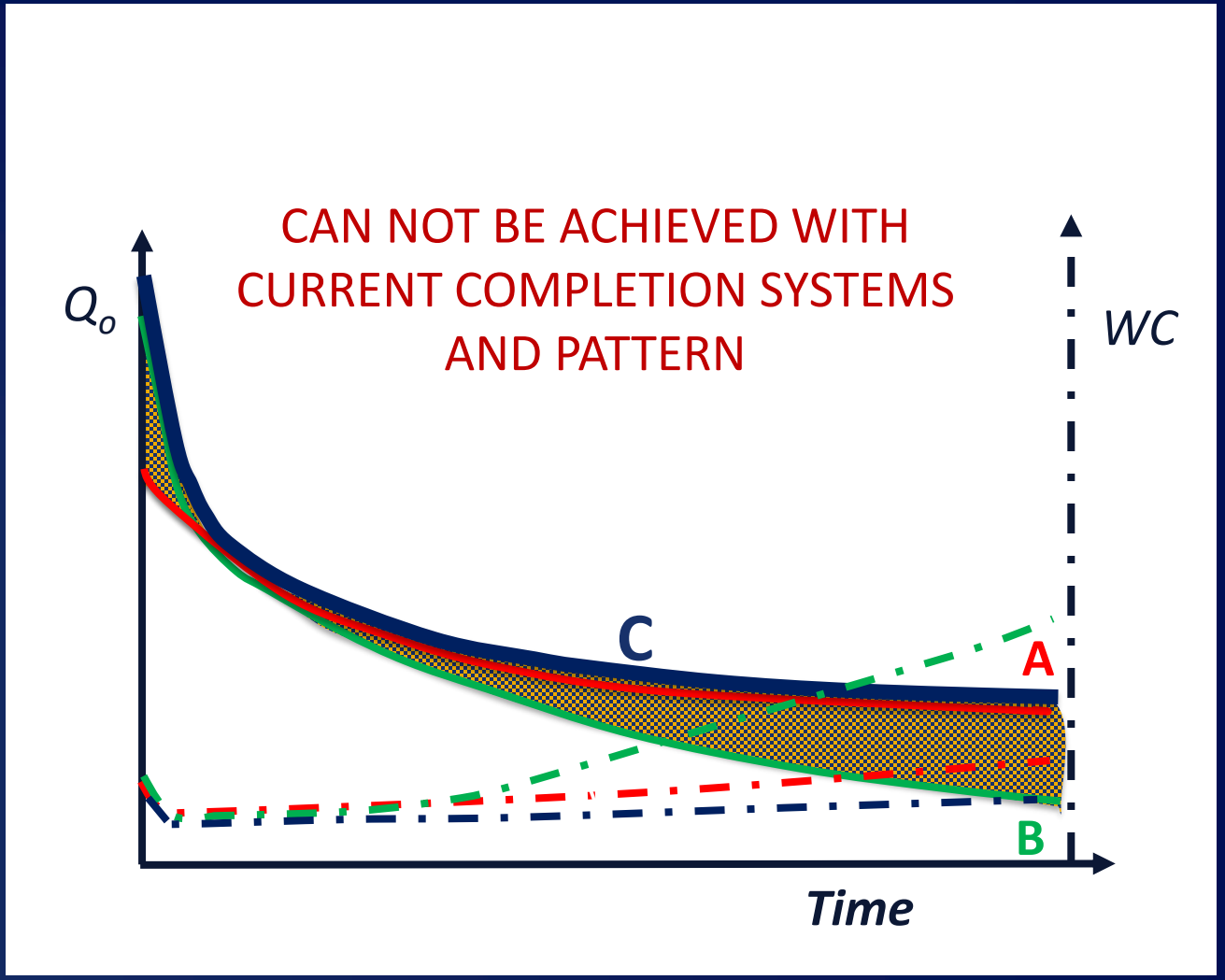
- Poor production management
- Poor water injection control

Goal

- Maximize oil production rate
- Reduce or delay water cut (WC) increase

…

- Increase recovery factor



Source: Butula K.K. et al SPE181983, 2016

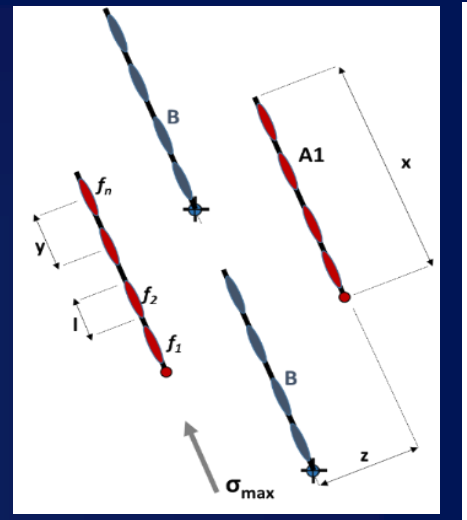
What to do?

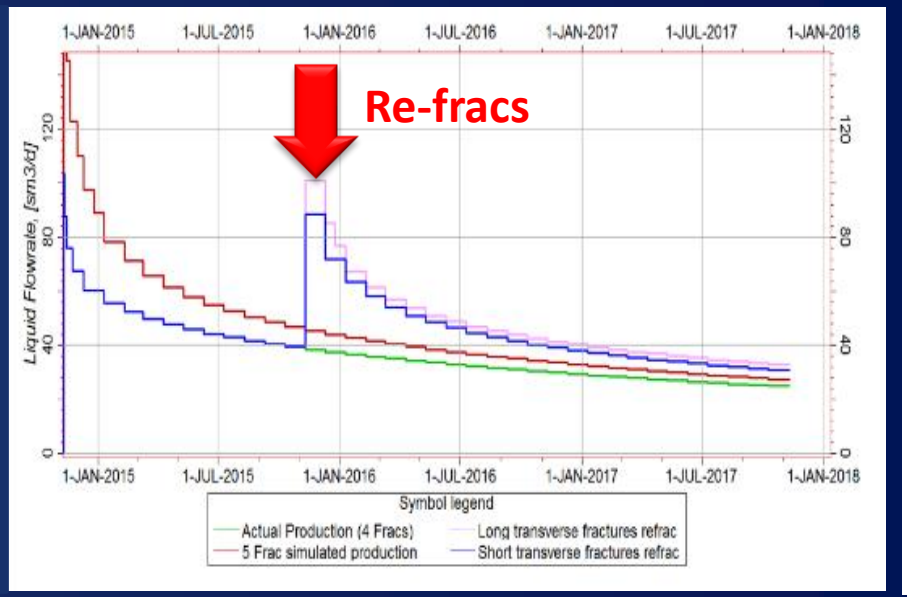
- Address reservoir pressure support

  & FDP patterns with HWMSF

- Review completion type

- Introduce re-fracturing old HWMSF





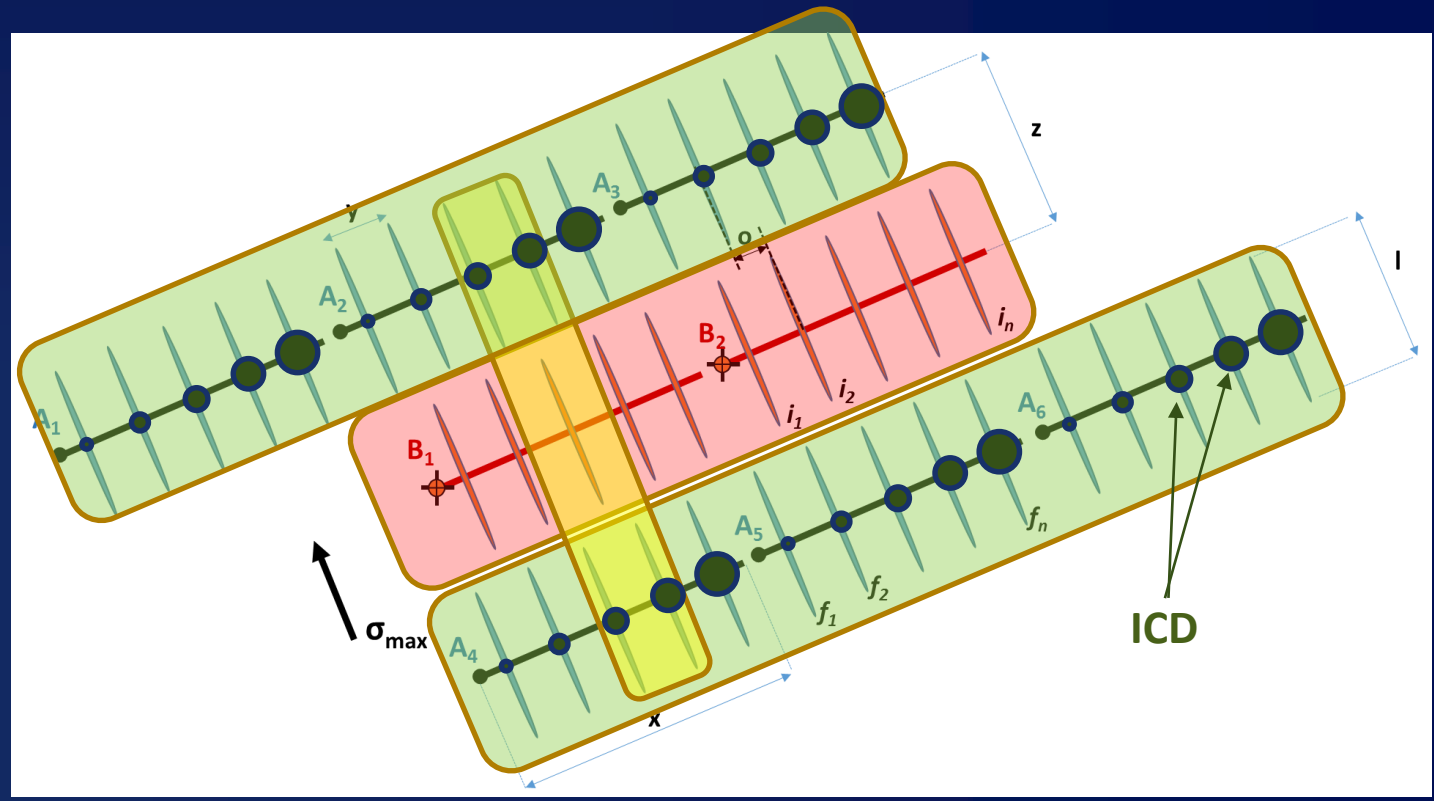
Source: slb.com/mss 15-CO-0015

Rethinking Pattern and Completion

Addressing the low–mid perm reservoirs requirements!

- Production and injection HWMSF completion design - similar

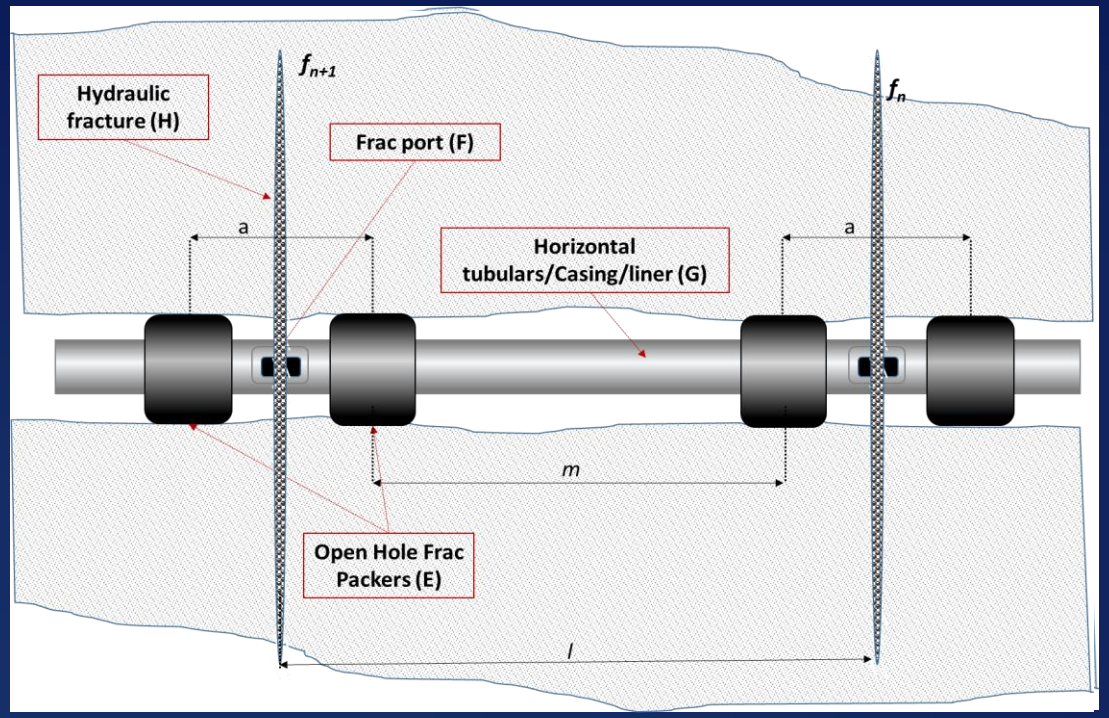
- **Maximizing production**
  - Multi frac completion
  - Perpendicular fracs
    - Stress orientation accounted
  - Pressure support
- **Water control:**
  - Inject below frac gradient
  - Controlled injection and…ICDs
  - Injector fracs offset to production fracs
- **Maximized recovery**
  - All of the above
  - Monitoring



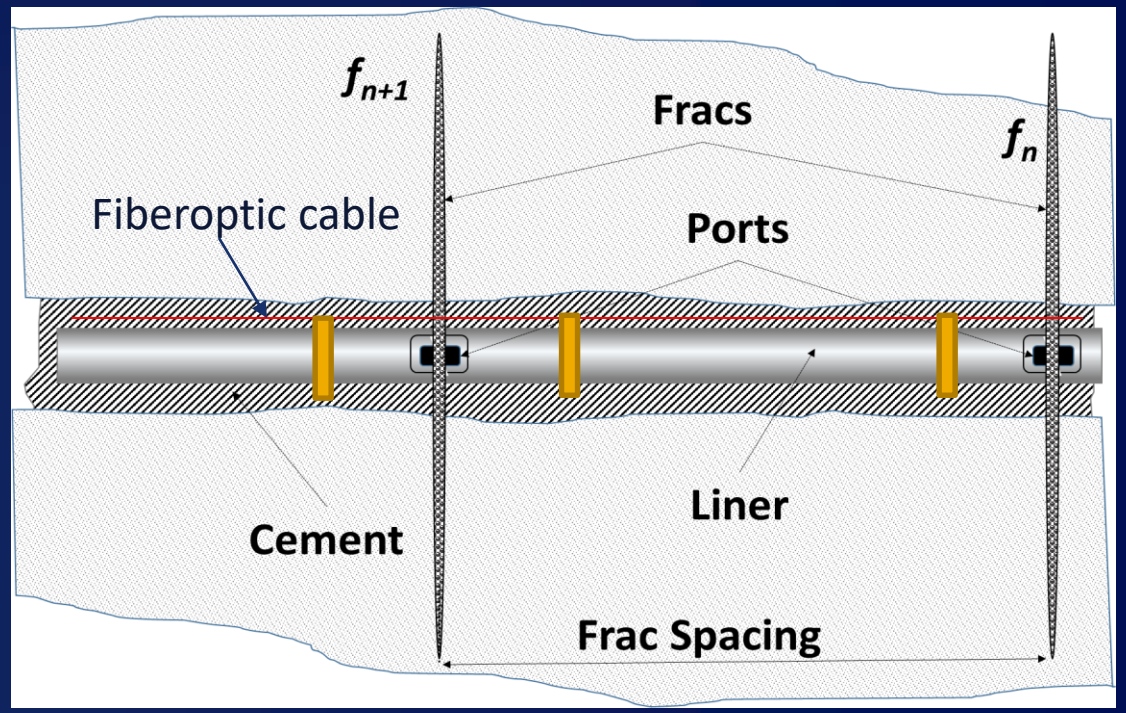
Source: Butula K.K. et al SPE181983, 2016

Controlling Fracture Placement

- Open hole liner with **closely spaced** packers, **re-closable ports and ICDs**



- Cemented liner and unique frac entry points



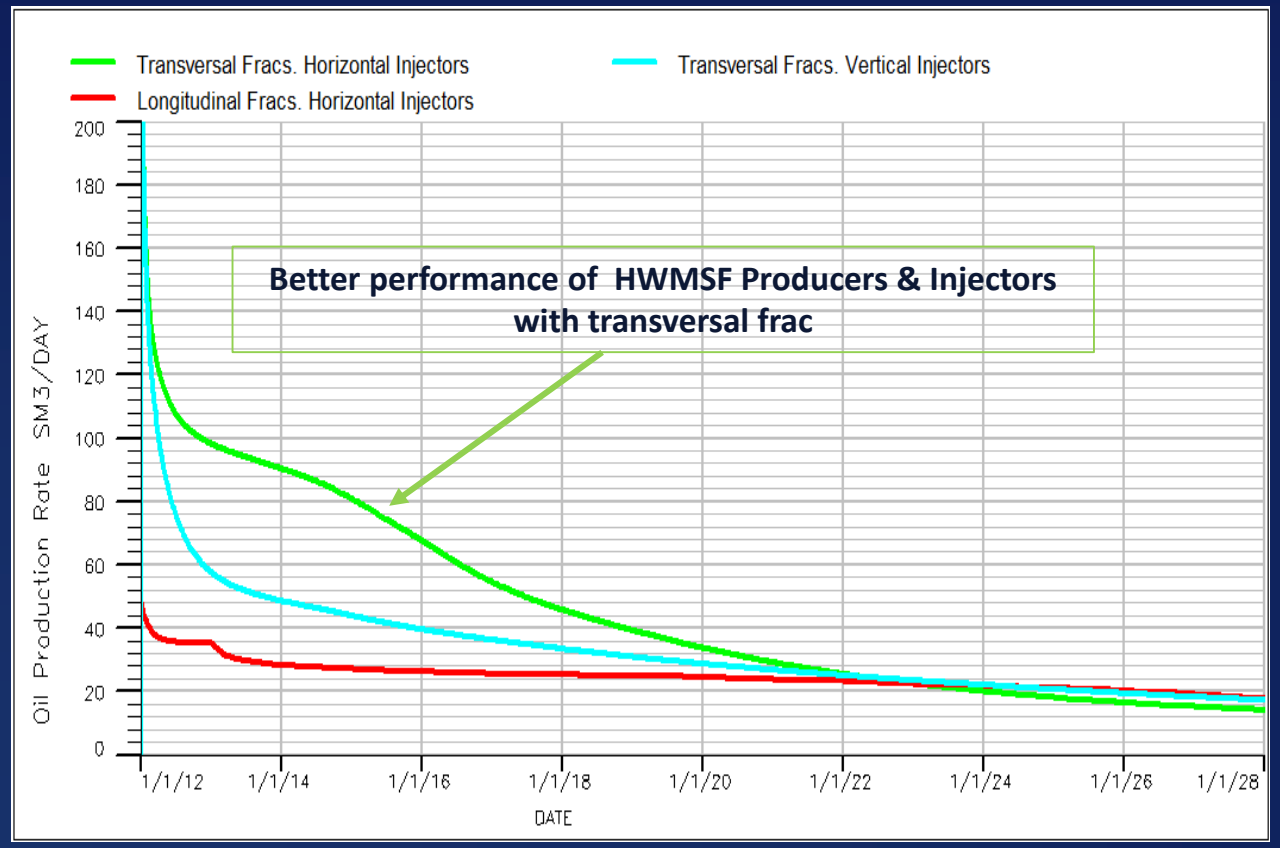
Source: Butula K.K. et al SPE181983, 2016

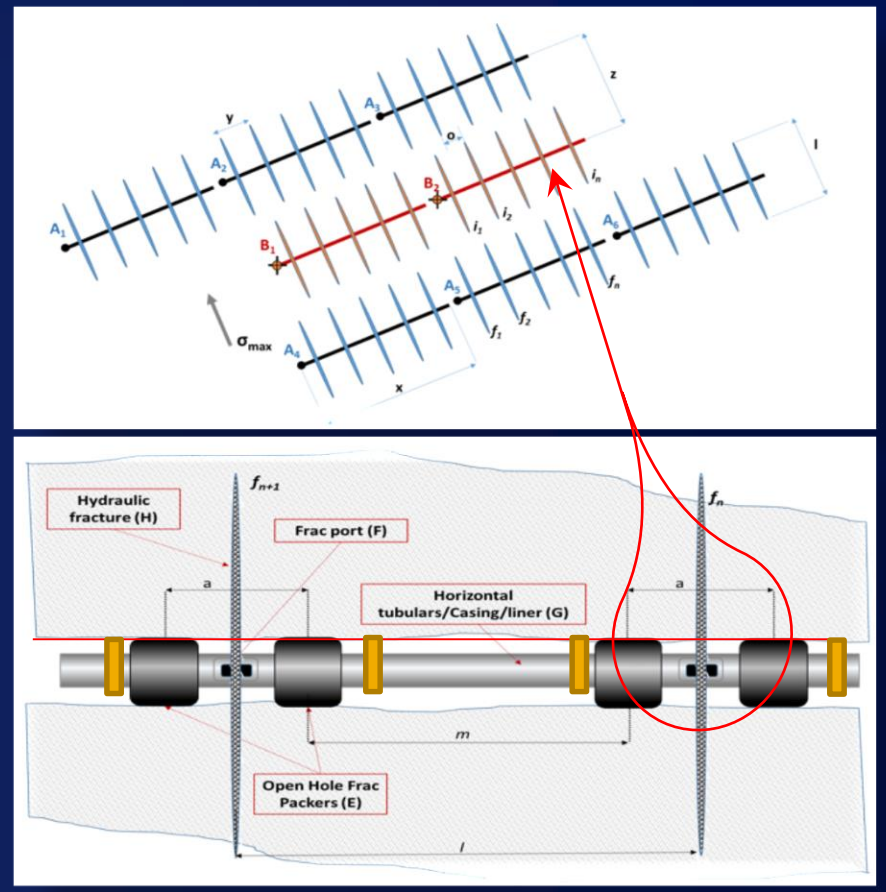
- Simplifying water conformance, work over and re-frac placement
- Monitoring using fiberoptic cable

Combining Completion and Pattern Design

- Hydrodynamic modeling and operational monitoring:
  - High initial oil rates & lower rate of decline
  - Minimize or delay WC increase

Source: Butula K.K. et al SPE181983, 2016

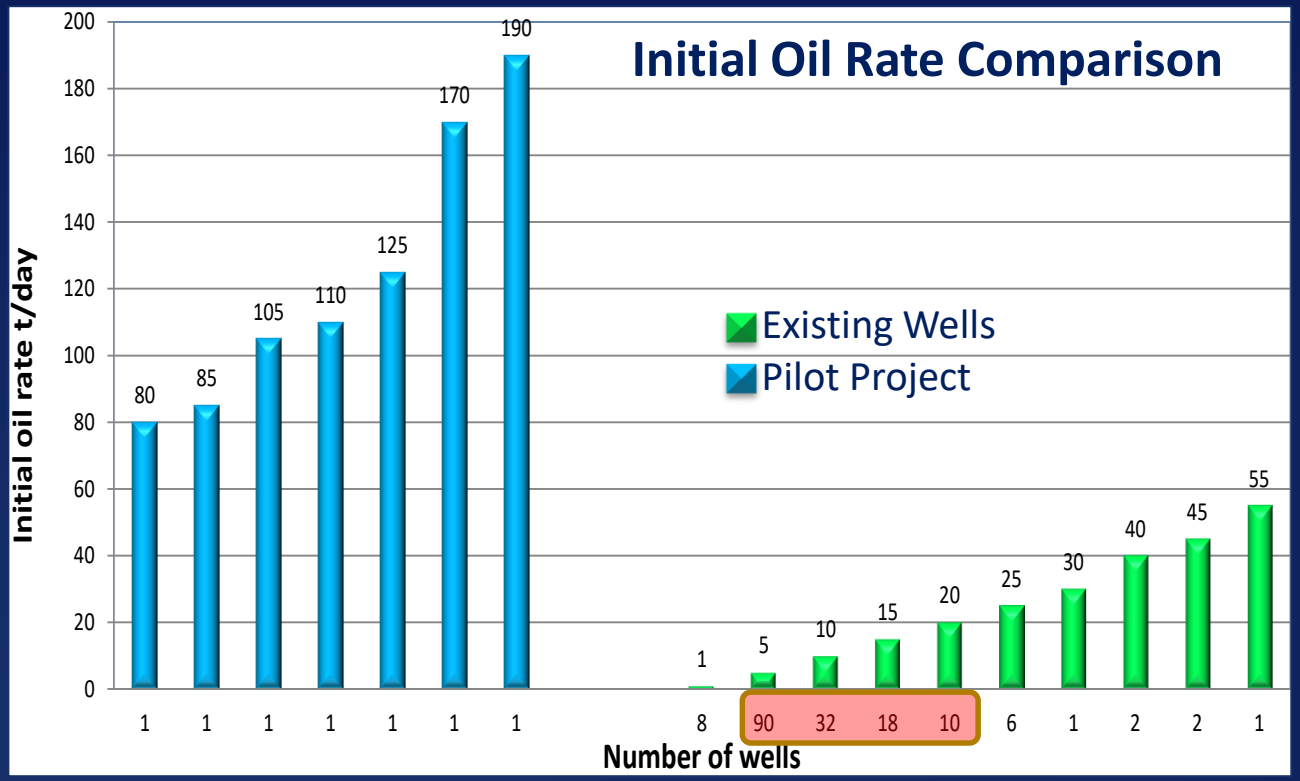




CASE STUDIES: NEW FDP AND COMPLETION

Pilot Project 1

Onshore, sector FDP test, low permeability oil reservoir

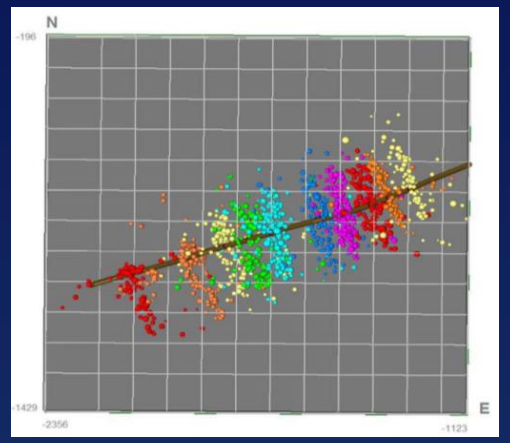


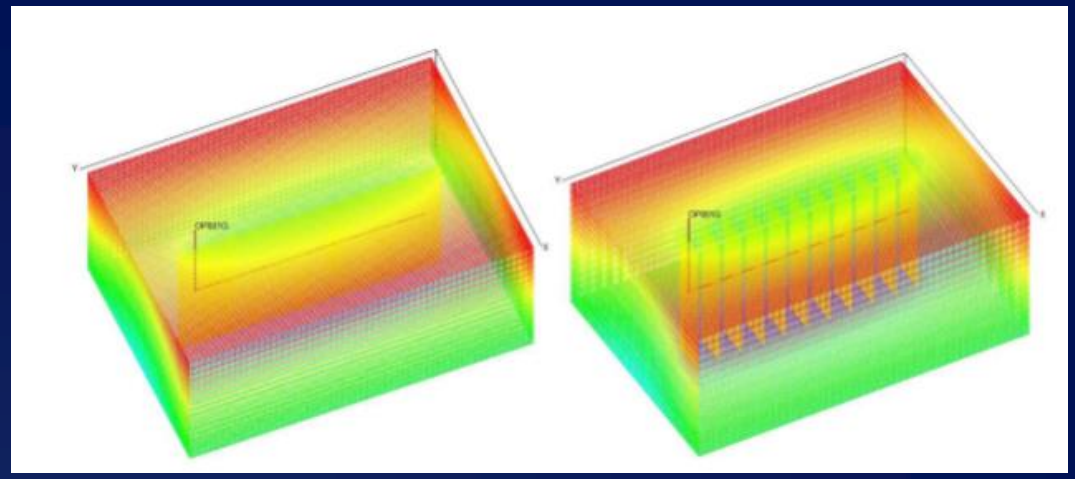
Source: Malyshev V. et al: SPE ATW Moscow, April 2013

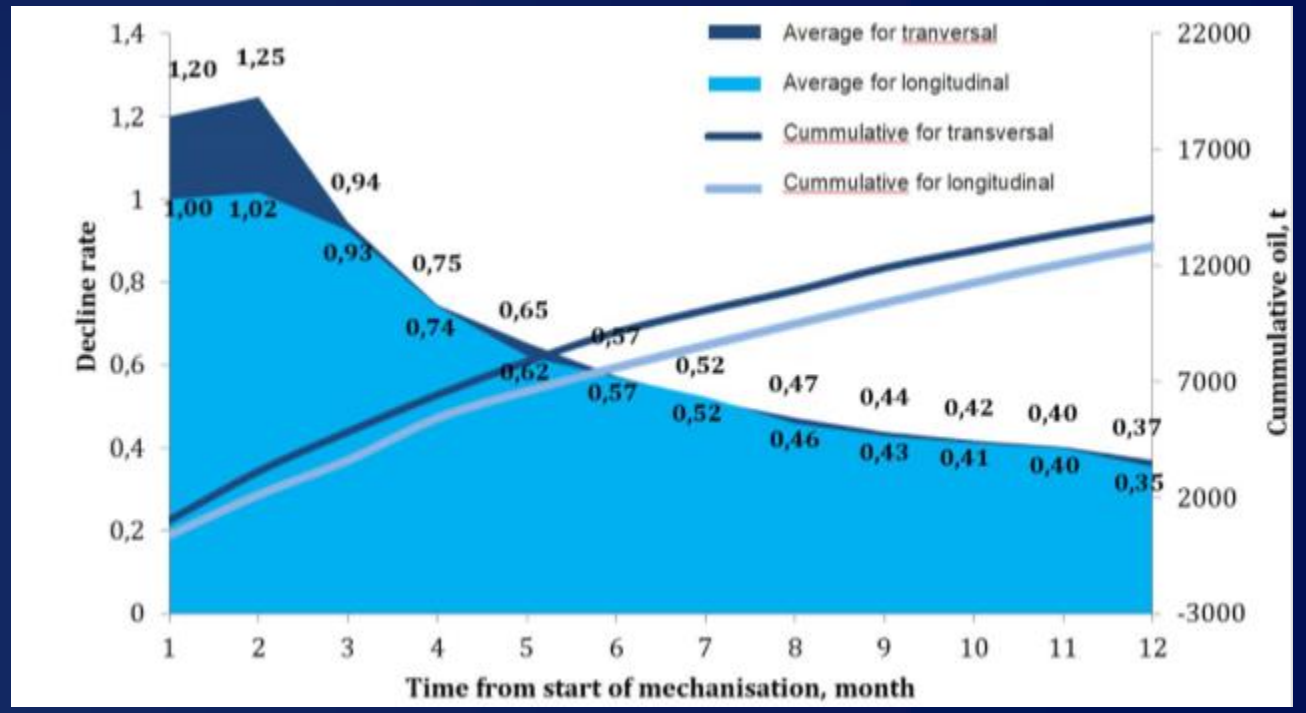
- Project:
  - New HWMSF injectors / producers pattern in sector under waterflood
  - Geomechanics modeling
  - New completion defining frac initialization
- Results:
  - Sector completed as designed
  - **Best initial rates for the field**

Pilot Project 2

- FDP sector changed from longitudinal to transversal fracs
  - k~0.75mD
- Monitoring:
  - Microseismic
  - PLT
  - Fiber optics
- Achieved predicted initial production increase
  - Injector well start in 2019





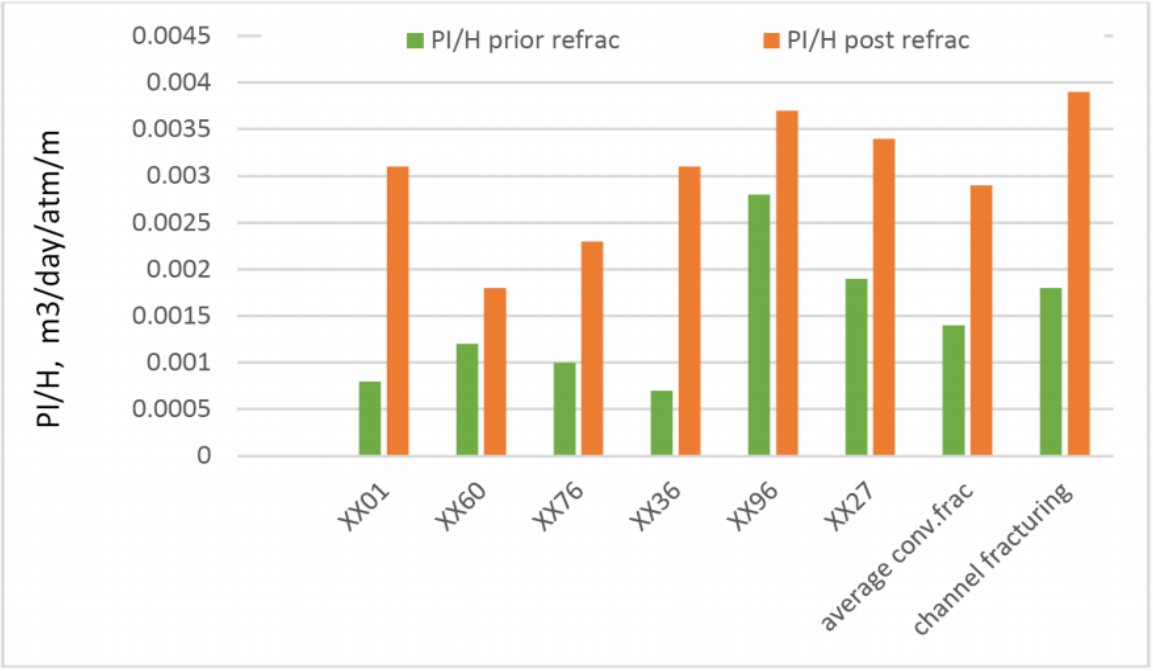


Source: Shurunov A et al. SPE-191581

RE-FRACTURING HORIZONTAL WELLS WITH MULTI STAGE FRACS

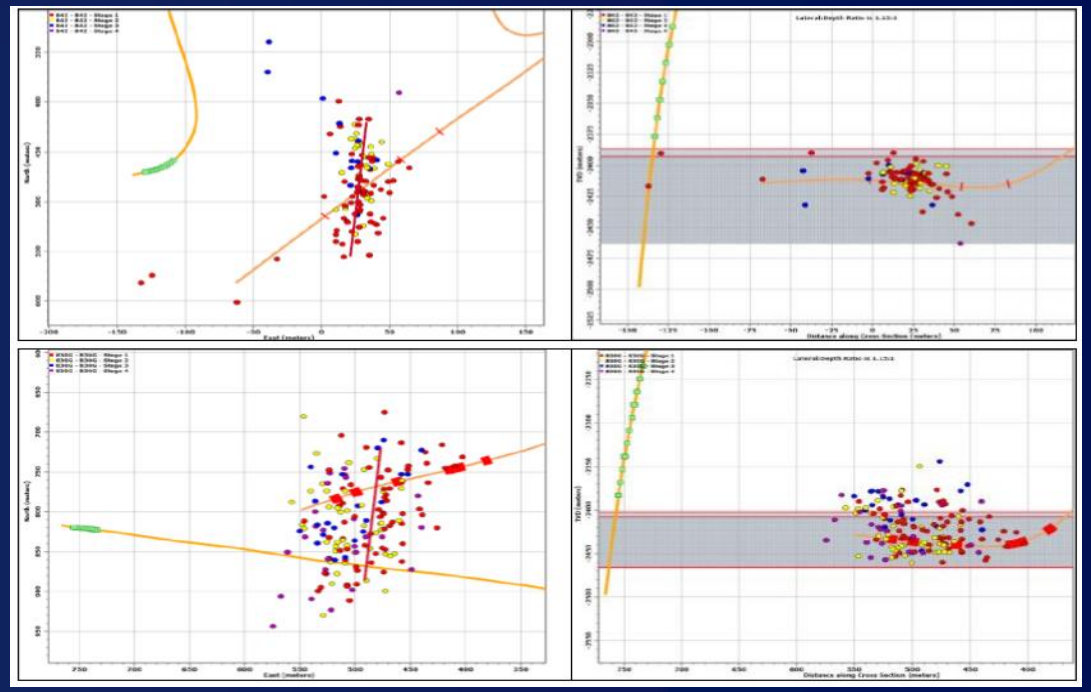
Known Facts of Re-fracs

- **Re-fracturing works**…in vertical wells
  - Fast production decline - in 6 months ~60% of initial rate;



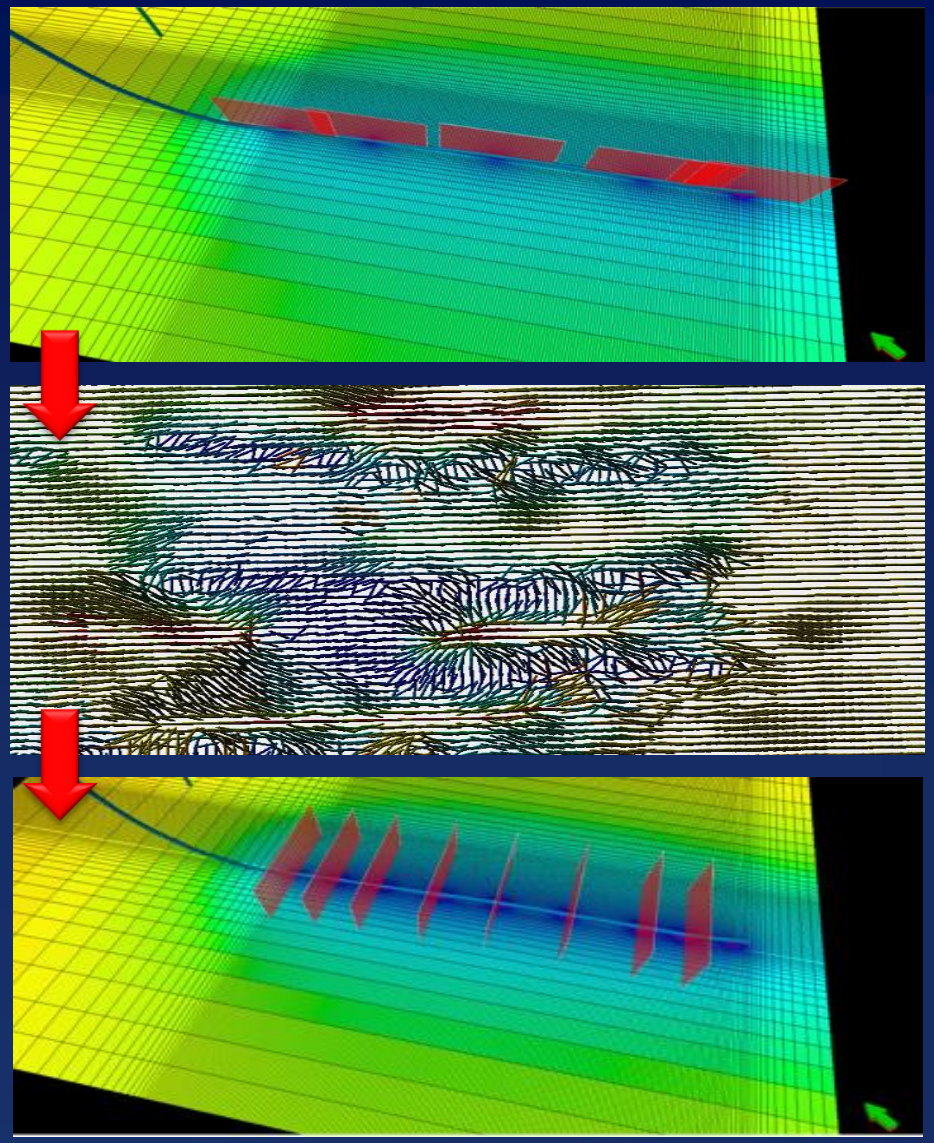
Source: Yudin A. et al SPE182133, 2016

- Re-fracturing HWMSF difficult:
  - "Blind frac" **can not work**... or why at all a HWMSF?



Source: Samoilov M. "Multi-stage fracturing and completion layouts Practice advantages and disadvantages" at SPE ATW September 2014

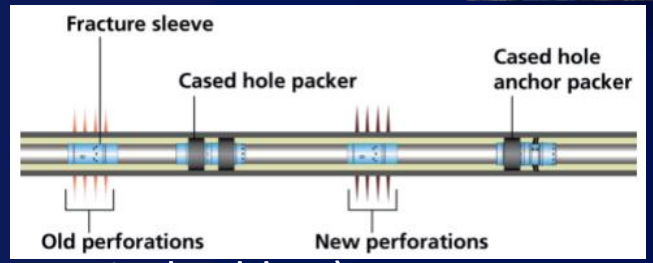
Complexity of Re-fracturing of HWMSF



Source: Butula K.K. et al SPE176720, SPE182020

- **Completion dependent**
- **Integrated engineering** feasibility studies required:
  - **Candidate selection**
  - **Well Preparation** - Milling, clean-up, flowback, start-up with CT
  - **Status** - flow profile measurement before/after re-frac
  - **Multi stage fracs** design/evaluation
  - **Modeling** existing fracs (pressure match)
    - Improvements for re-fracs
  - **Production** history matching and **forecast**
  - **Geomechanical** 1D, 3D and 4D sector model
    - Frac initiation
    - Frac geometry in depleted zone
    - Frac re-orientation
  - **Technology:**
    - **Slim hole** completions
    - Dynamic **diverter** material design
    - Other…
  - **Measurements** (Micro seismic, fiber optical cable…)
  - Final **project economics** evaluation and potential advantages

Source: Hildek et alSPE180236

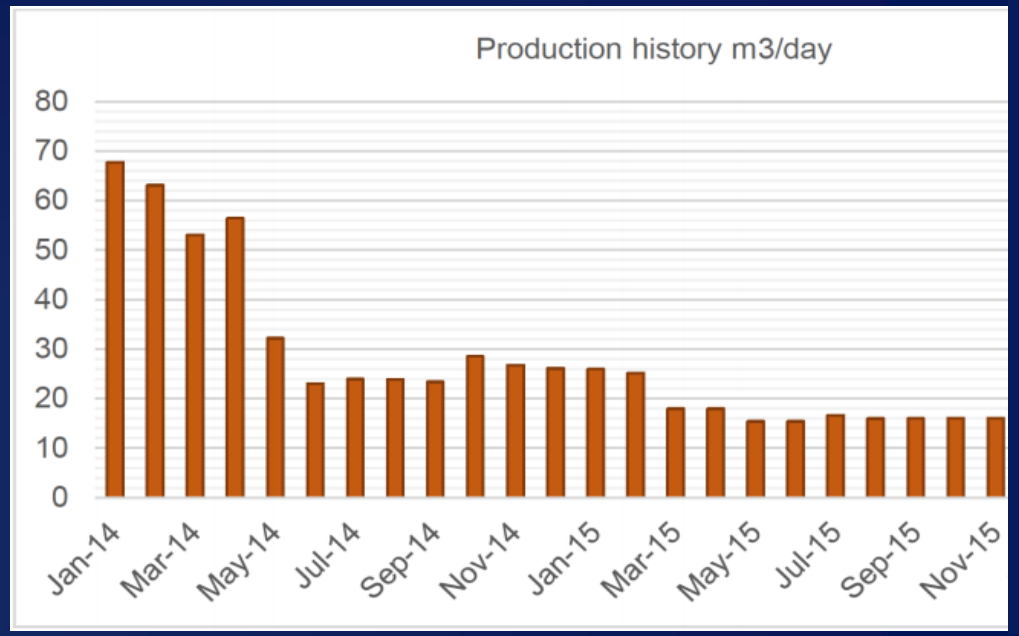


CASE STUDIES: RE-FRACTURING

Pilot Project 3

Re-fracturing using Coiled Tubing (CT) **re-closable ports** completions

- Project:
  - Test HWMSF using **re-closable** frac ports for re-fracturing
  - Low permeability oil reservoir
- Results:
  - Selective port frac
  - Significant performance increase

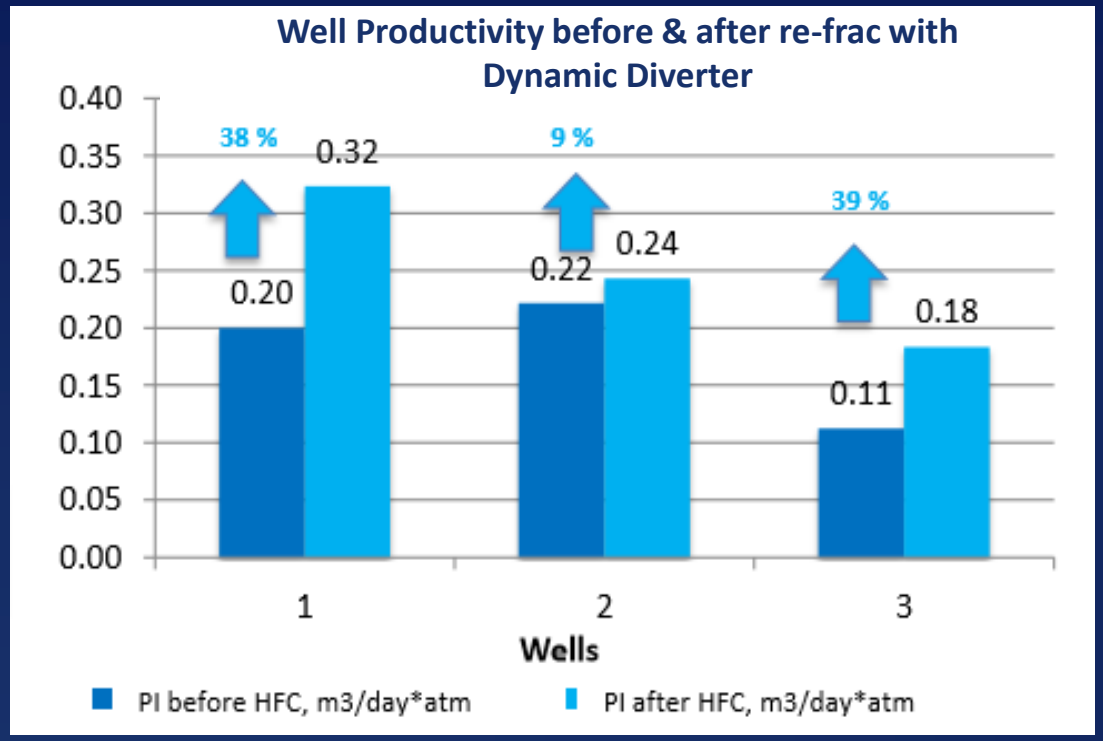


Source: Burdin K. et al, SPE182123, 2017

Pilot Project 4

SPE DISTINGUISHED LECTURER

Re-fracturing HWMSF common completions using **Dynamic Diverter**



Source: Faizulin I. et al "Experience of MSHF implementation in JSC Gazprom Neft. Further steps" SPE ATW Moscow September, 2016

- Project:
  - **Dynamic Diverter** for conventional reservoirs
  - 3 HWMSF producers in sector under waterflood
  - Low permeability oil reservoir
  - Depleted sector
  - 4D Geomechanics
- Results:
  - PI improvements achieved & WC increase
  - Model:
    - No re-orientation of re-fracture
    - Fracture containment in depleted oil zone

HWMSF in Waterflood: Conclusions and Recommendations

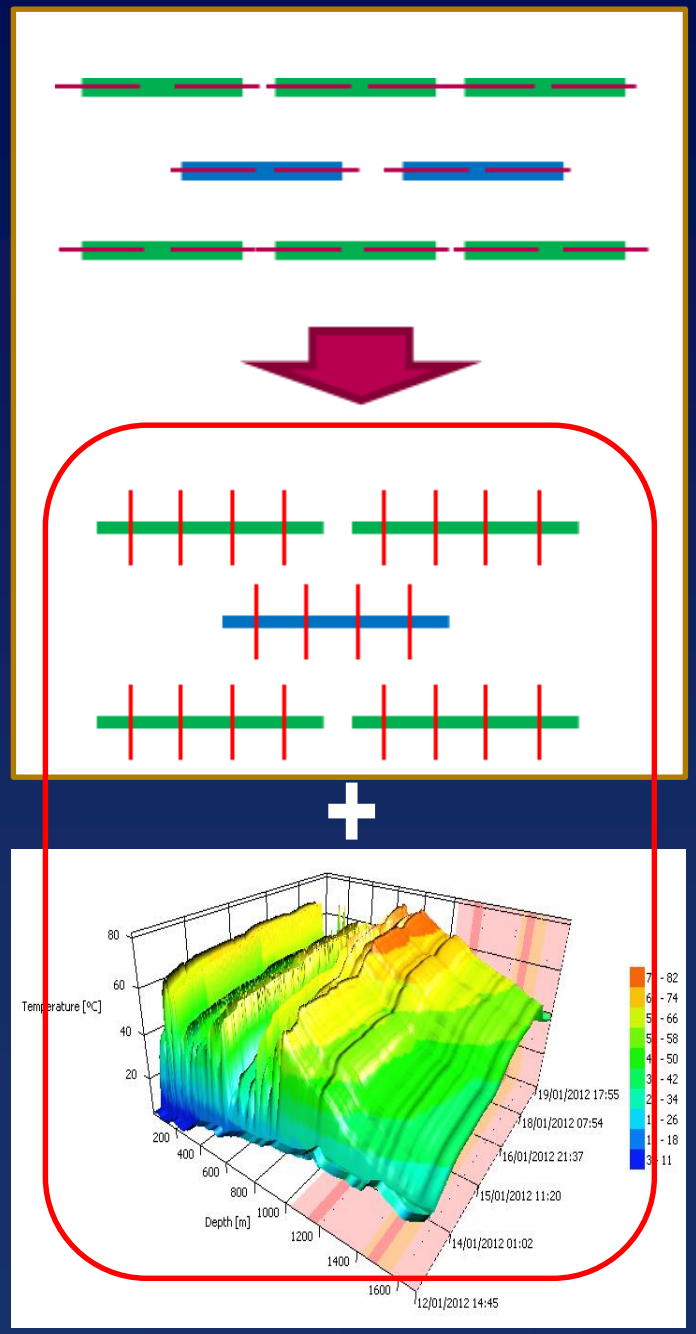
SPE DISTINGUISHED LECTURER

- **Current completion and field development patterns are plagued with multiple issues**

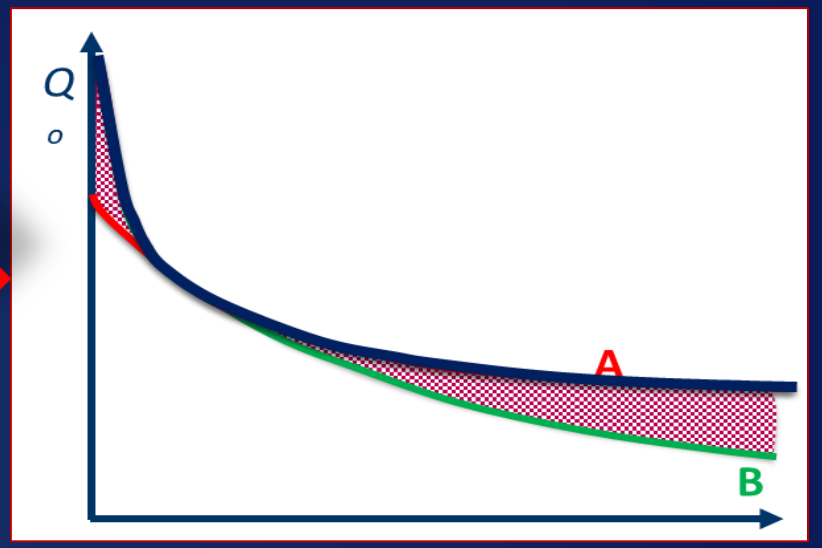
- **New wells:**
  - **Consider new completion and pattern**
    - Limited incremental CAPEX
  - The pattern provides:
    - Maximizing hydrocarbon recovery
    - Minimize injection pressures
    - Minimizing water breakthrough
  - The well construction provides:
    - Highest initial and late time flow rates
    - Maximum injection and production rates
    - Maximum contact with the reservoir
  - The completion allows for:
    - Reduced risk of early water breakthrough
      - Designed/Controlled/Monitored water injection
    - Simplest and most cost effective **re-fracturing**
  - Extensive **integrated modeling**

- **Old wells:**
  - **Re-fracturing**
    - "Blind fracs" do not work
    - Well preparation with CT needed
  - **Re-fracturing** with Dynamic Diverter **possible**
    - Limited risks
    - Measurements available
    - Simplicity and speed
  - Extensive **integrated modeling**
    - Reservoir - Geomechanics – Frac completion
      - Fracture re-orientation
      - Fracture geometry
  - Alternative re-fracturing methods costly
  - Water shut off methods costly

HWMSF Take Away



- HWMSF in conventional reservoirs are here to stay
- Poor productivity from current completion design and pattern in waterflood
- Integrated engineering
- Rethink FDP pattern and completion in waterflood



- New technology/engineering with integrated solution to boost economics and improve recovery factor

- Adequate and controlled injection needed
- Monitoring feasible and extremely informative
- Starting re-fracturing

SPE DISTINGUISHED LECTURER

Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation
Visit SPE.org/dl

SPE International

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

33

Reference

- SPE102633 M. Butter et al. 2006
- SPE182133 Yudin A. et al. 2016
- SPE168288 Burdin K. et al. 2014
- CT Times #59, March 2017, ISSN1817-3300
- Middle East Well Evaluation Review #16, 1995
- SPE181983 Butula K.K. et al. 2016
- Veremko, N.A. ”Optimization formation production in Western Siberia using HW MSF” Lukoil SPE Moscow Section Presentation, 7th February,2012
- SPE182123 Burdin K. et al. 2017
- SPE182133 Yudin A. et al. 2016
- Samoilov M. “Multi-stage fracturing and completion layouts Practice advantages and disadvantages” at SPE ATW September 2014
- SPE171277 Ablaev A. et al. 2014
- SPE176562Davletbaev A. et al. 2015
- SPE 120749 Kuzmina et al. 2009
- Baikov V.A. et al. 2011
- Patent RU#2515628 C1, Baikov V.A. et.al. 2014
- Latypov et al. NefteGaz Journal Oct. 2013
- Asmandiarov R. et al. “Monitoring HWMSD: comparison of decline analysis , mini-frac, and PLT using Y-tool”, SPE ATW Samara, 2014
- Faizulin I. et al “Experience of MSHF implementation in JSC Gazprom Neft. Further steps” SPE ATW Moscow September, 2016
- Ogorodov A. “Easy Frac Repeated Multistage Hydraulic Fracturing (MHF) in Horizontal Wells” SPE ATW Moscow , 2016

Metric / SI Unit Conversion

SPE DISTINGUISHED LECTURER

Metric/ SI Unit	Factor			Oilfield Unit
atm	×	1.46959488	E + 01	psi
bar	×	1.45037738	E + 01	psi
°C	×	(1.8×°C)+32		°F
cm	×	3.93701	E + 01	in
m	×	3.28	E + 00	ft
m^3	×	6.28981	E + 00	BBL
ton	×	2.20462	E + 03	lbm