SPE YP Tech Talk

Optimization Through Application of Hydrocarbon, Water and Proppant Tracers

ProTechnics

Chad Senters 1-19-2017

Outline

- Introduction
- Why Trace – Diagnostic Introduction and Discussion
- Oil/Water Flow Assurance
- Dissolvable Systems
- Diverter Analysis
- Production Analysis
- Refracturing
- Targeted Perforating / Natural Fractures
- Cost Optimization
- Isolation Effectiveness
- STACK Paper

Global Technology Team

ProTechnics

- 11 Technical Experts focused on providing solutions and maximizing the delivered diagnostic value
- Regional Engineering Advisors located in all major basins
- Leveraging extensive technical database, maximizing the delivered diagnostic value
- Industry experts in refracturing, diversion, and completion optimization
- Deliverables customized to address primary purpose of tracing
- 3D visualizations for inter-well communication
- HFTS (Hydraulic Fracturing Test Site) – Wolfcamp JIP partially funded by DOE, Core Lab
- Many SPE publications and presentations

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Recent SPE Publications

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SPE papers co-authored by the GTT Recently

- **Evaluating & Optimizing Refracs – What the Diagnostics are Telling Us (#181676)**
- **Wolfcamp Completions - Lessons … to Optimize Existing Drilling and Stimulation Practices (#181679)**
- **Uinta Basin - Reducing Completion Costs and Identifying Horizontal Well Targets (#181721)**
- **STACK - Evolution of Completion Practices (#181441)**
- **Miss Canyon GOM – Frac Pack Case Histories … Proppant Tracing and Gravel Pack Logging (#181658)**
- **Haynesville Re-stimulations Case – Improving Lateral Coverage … incremental gas recovery (#2443071)**
- **Refrac Diagnostics Provide a Second Chance to Get it Right (#174979)**
- **Reducing Costs and Optimizing D&C Efficiencies … Using Completion Diagnostics (#174844)**
- **Granite Wash Targeted Perforating … Traced Cement Spacer Leakoff (#174851)**
- **Determining the Effectiveness of Isolation Techniques Using Completion Diagnostics and Production Analysis – (#179175)**
- **Granite Wash Optimization – Validating Completion and Production Techniques (#170923)**

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SPE Paper 174979
Refracs – Diagnostics Provide a Second Chance to get it Right

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Why Refrac?

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- Develop new reserves (contact new rock)
- Initial completions exhibit inconsistent/poor proppant coverage across lateral
- Employ new technologies, completion designs, and/or fit-for-purpose fluids
- Restore frac conductivity or re-energize natural fissures
- Operational problems with original completions
- “Protection Fracs” to minimize shared drainage areas
- Current commodity prices require max production at the lowest possible cost

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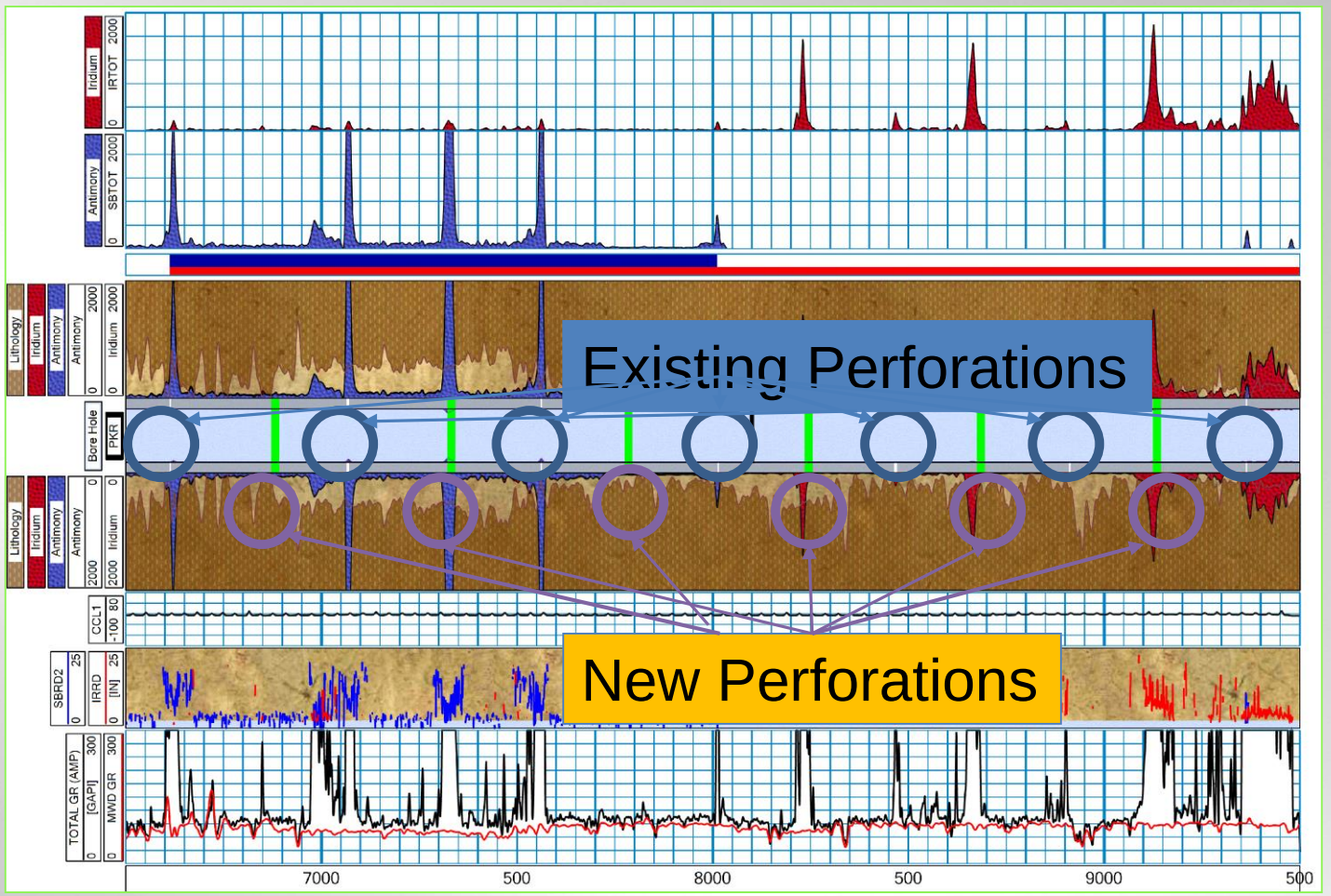
Beginning the Refrac Process

- Which wells are the best refrac candidates?
- At what point in time should we consider re-stimulation?
- How do we maximize new fracture network development?
- Is communication between wells an issue?
- Should we recharge offsets prior to refracing? Protection fracs?
- What should be our incremental production expectations?

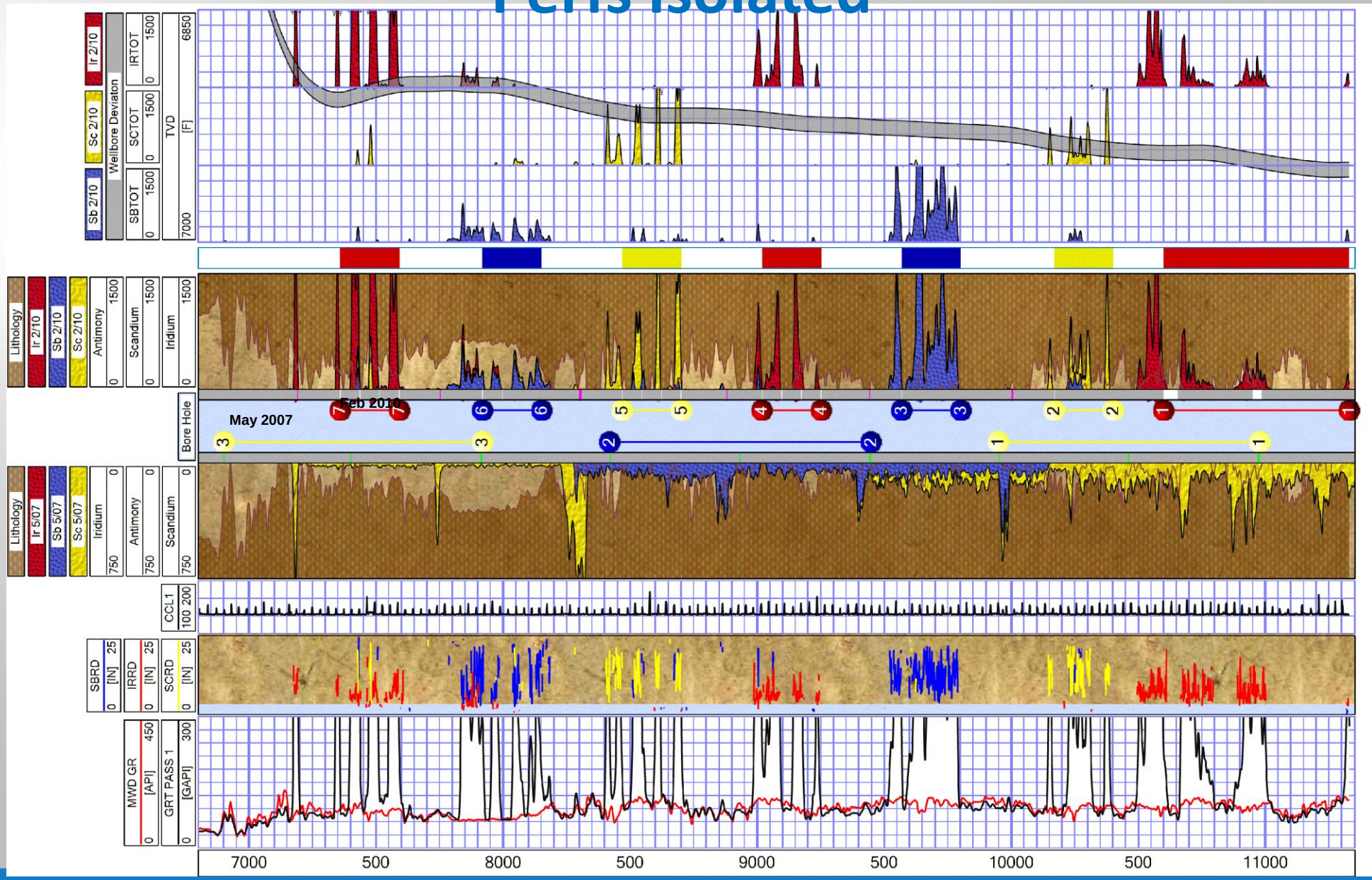
Refrac Design Questions

- Should we re-perforate, if so how and with what?
- How do we isolate the old perfs/depleted zones?
- What is the best diversion technique?
- How many refrac stages?
- How much fluid and prop should be used?
- At what rate should we refrac?

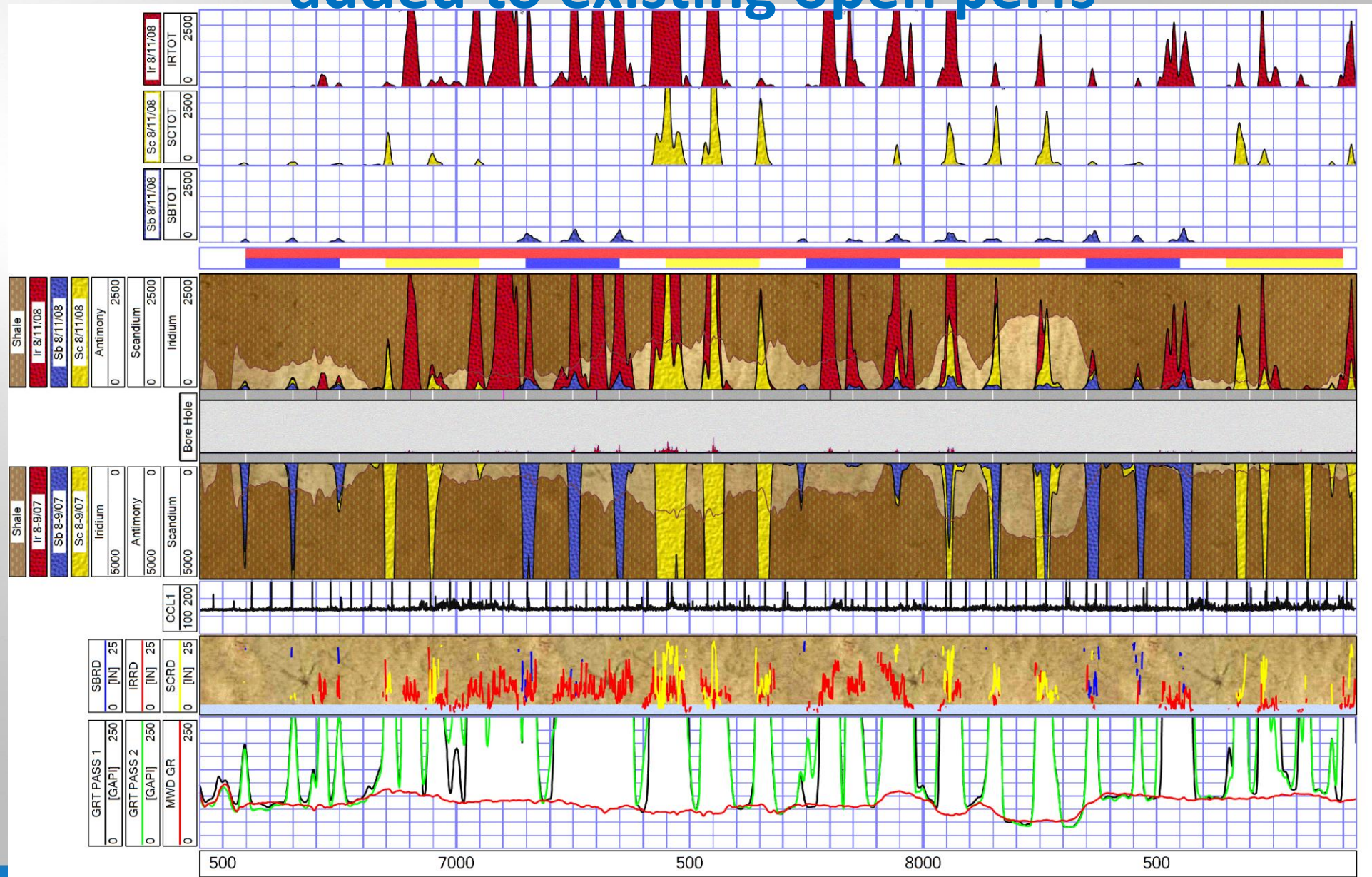
Early 2 Stage Barnett Horizontal Refrac – No Isolation or Diversion



7 Stage Barnett Horizontal Refrac – Existing Perfs Isolated



Marcellus Single Stage Refrac – New perfs added to existing open perfs



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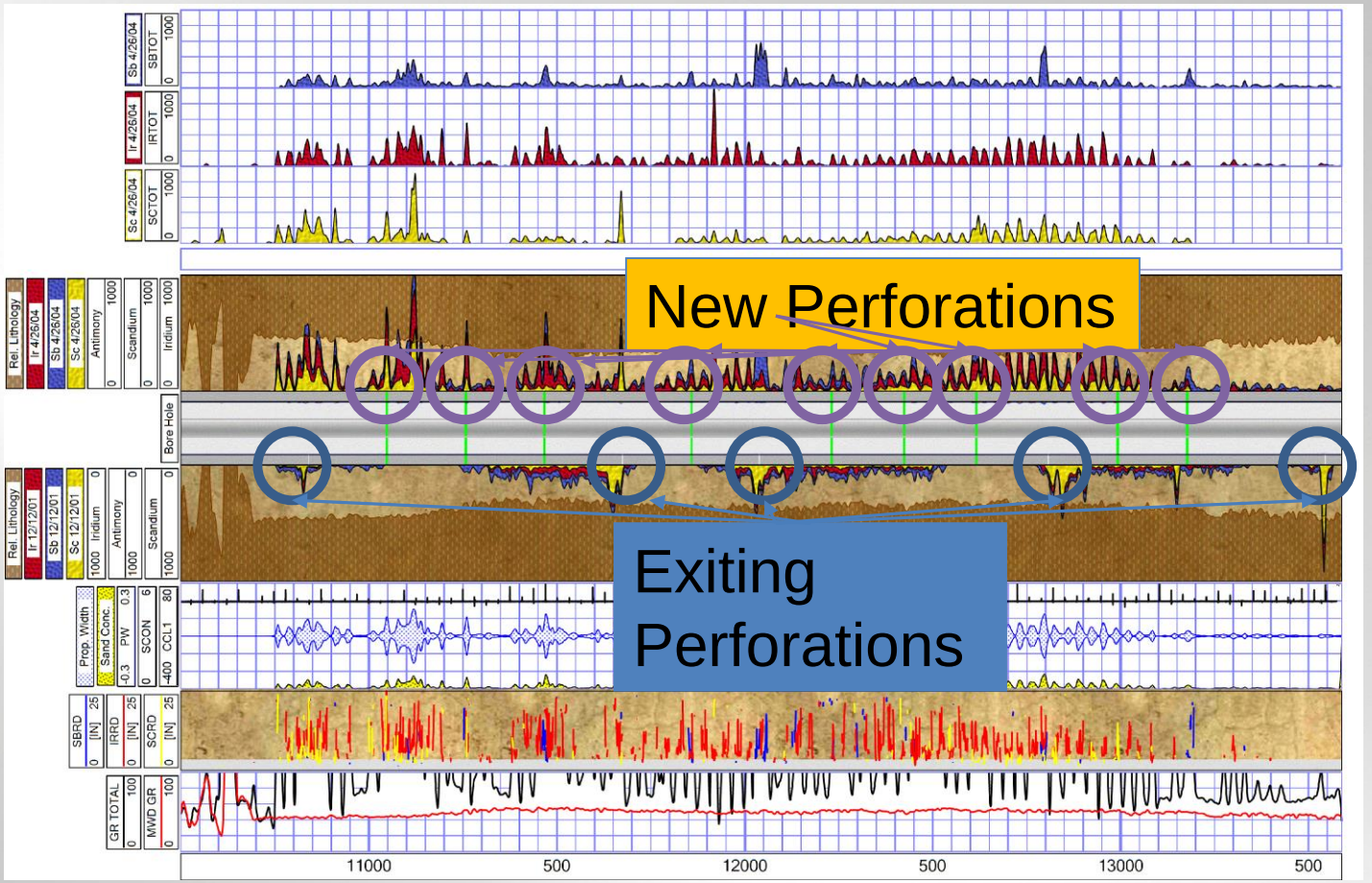
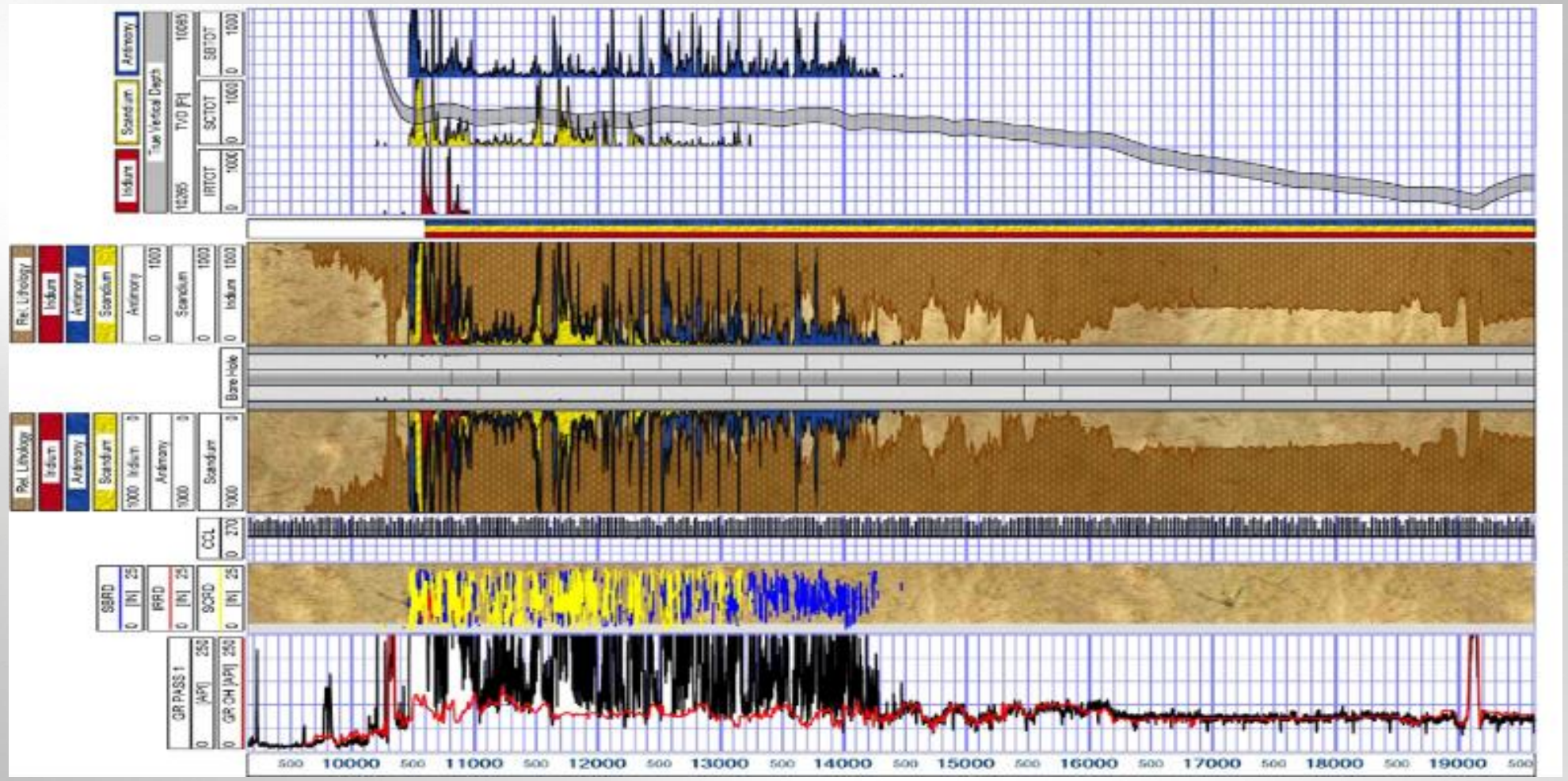
Bakken Single Stage Refrac – New perfs added to existing perfs



Diversion

- Key technology in avoiding old partially depleted perforations
- Wide array of new products are being introduced to address this need
- Some diversion techniques are now being applied to optimize new well compl.
- Some critical considerations
  - What is the most cost-effective diversion?
  - What is the best way to evaluate diversion success?
  - Why do sand plugs work in some areas?
  - Is there any concern with polymers not degrading?

Proppant Diverting Back to Heel



Refrac Lessons Learned

- Every basin is different – No one size fits all
- Candidate selection is critical
- Early completions in the completion/stimulation evolution are a good start
- Maximize new rock contact by adding new perforations
- Evaluate and manage offset well communication
- Longer laterals are more challenging to get good proppant coverage
- Diversion can change offset communication profile

The Analytical Conclusions

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- It is difficult to treat more than 2300’ of lateral, tendency to preferentially treat the heel
- Over 2/3 of the studied refracs responded favorably to re-stimulation
- Average incremental EUR gain from refrac of 658 MMCF (gas) and 200 MBO (oil)
- 100% of the analyzed wells had at least some “new” perforations stimulated
- Diversion techniques are not totally effective at contacting new rock
- Pumping diversion materials too early can lead to a reduction in re-stimulated length
- Fluid diagnostics can be utilized to evaluate inter-well communication
- Hydrocarbon tracers also offer a future option to evaluate effective drainage areas

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SPE # 181676
Evaluating and Optimizing Refracs
What the Diagnostics are Telling Us

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Refrac Lessons Learned

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- SPE # 174979 • Refracs – Diagnostics Provide a Second Chance to Get it Right
- Every basin is different
- Candidate selection is critical
- Determine primary re-stimulation goal up front
- New perforations effectively placed will maximize new rock contacted
- Longer laterals are more challenging to get good proppant coverage
- Current Diversion techniques are not totally effective at contacting new rock
- Pumping diversion materials too early can lead to a reduction in re-stimulated length
- Evaluate & manage offset well communication
- Diversion can change offset communication profile

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Classification, Evaluation, and Data Groupings

- Well trajectory – Vertical or Horizontal
- Isolation Method
  - Mechanical Diversion (MD)
  - Particulate Diversion (PD)
  - Other Diversion (OD)
  - No Diversion (ND)

Grouping of All Wells by Isolation Type

Perf Isolation Type	Total # Wells	Horizontal Wells	Avg. Refrac IP/Orig IP	Avg. Daily Prod Gain	Lateral Restim Ft	Avg. % Lateral Restimulated	Avg. % Clusters Restimulated
MD	39	35	52%	140	2745	92%	88%
ND	20	6	98%	104	958	85%	90%
OD	35	25	42%	111	2073	89%	74%
PD	29	23	66%	201	2644	73%	64%
Averages	-	-	65%	139	2105	85%	79%

Vertical Refrac Analysis

- 34 vertical re-stimulations were evaluated
- The Barnett formation had the most traced vertical wells
- 40% of the refracs used no diversion and had the highest BOE Gain

Perf Isolation Type	Total # Wells	Avg. Refrac IP/Orig IP	Avg. Daily Prod BOE Gain
ND	14	114%	105
OD	10	47%	48
PD	6	116%	1
MD	4	74%	13

Barnett Shale Refracs

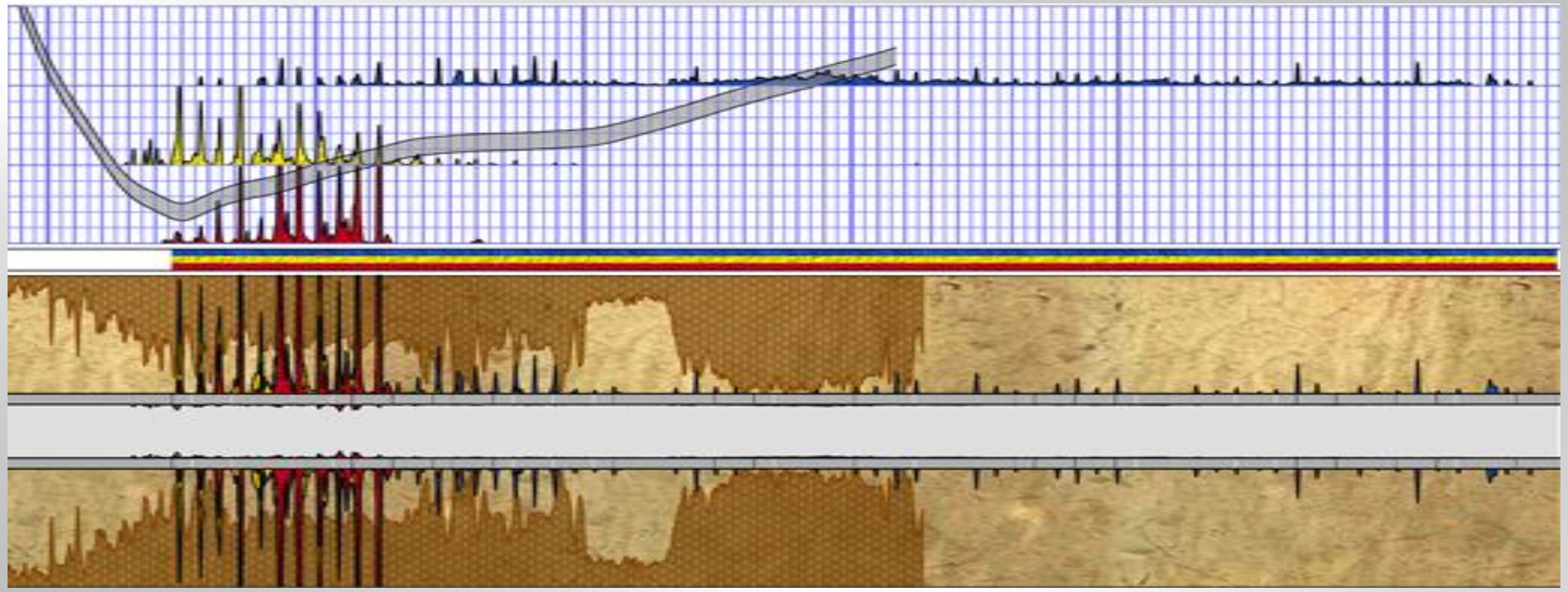
- Most active basin for refracs
- Favorable rock – highly brittle, minor differences in max/min stress
- Early in the development of unconventional resources
- Over 50% of the horizontal refracs utilize mechanical isolation

TYPE OF ISOLATION	# OF WELLS	REFRAC IP % vs ORIGINAL %	DAILY NET PROD INC (BOE/D)	AVG. RESTIM FOOTAGE	RESTIM OF ORIG LATERAL	% CLUSTERS STIMULATED
MD	32	51%	139	2619	92%	87%
ND	5	54%	120	1314	70%	81%
OD	14	44%	122	1514	87%	79%
PD	2	51%	117	737	55%	45%

Eagle Ford Refrac Utilizing X-Linked Gel & Diversion

- Original plug and perf completion in oil window
- Refrac utilized 20# X-Link gel with 30/50 sand and 25 diversion stages
- 3 Proppant tracers were utilized, each tracing ~ 1/3 of the stages
- Extent of lateral coverage being re-stimulated declined over time
- Application of diverter stages did not promote new rock contact
- 850’ heel section was preferentially stimulated
- Ineffectiveness of diversion resulted in less than 30% of the lateral being effectively stimulated

Proppant Tracer Log of Eagle Ford Refrac



Wolfcamp Case History – Diversion Effects on Inter-well Communication

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- The Challenge – How do you effectively re-stimulate the entire 5000’ lateral?
- Lateral is surrounded by 3 horizontals and 7 vertical wells
- New perfs were added long the entire lateral
- Multiple mini-diversion stages were pumped throughout the refrac
- Refrac was traced with proppant and fluid tracers
- Different proppant tracers and fluid tracers were pumped in 1/3 increments
- Diagnostics indicate heel was preferentially stimulated
- Fluid diagnostics quantify increased inter-well communication at end of job

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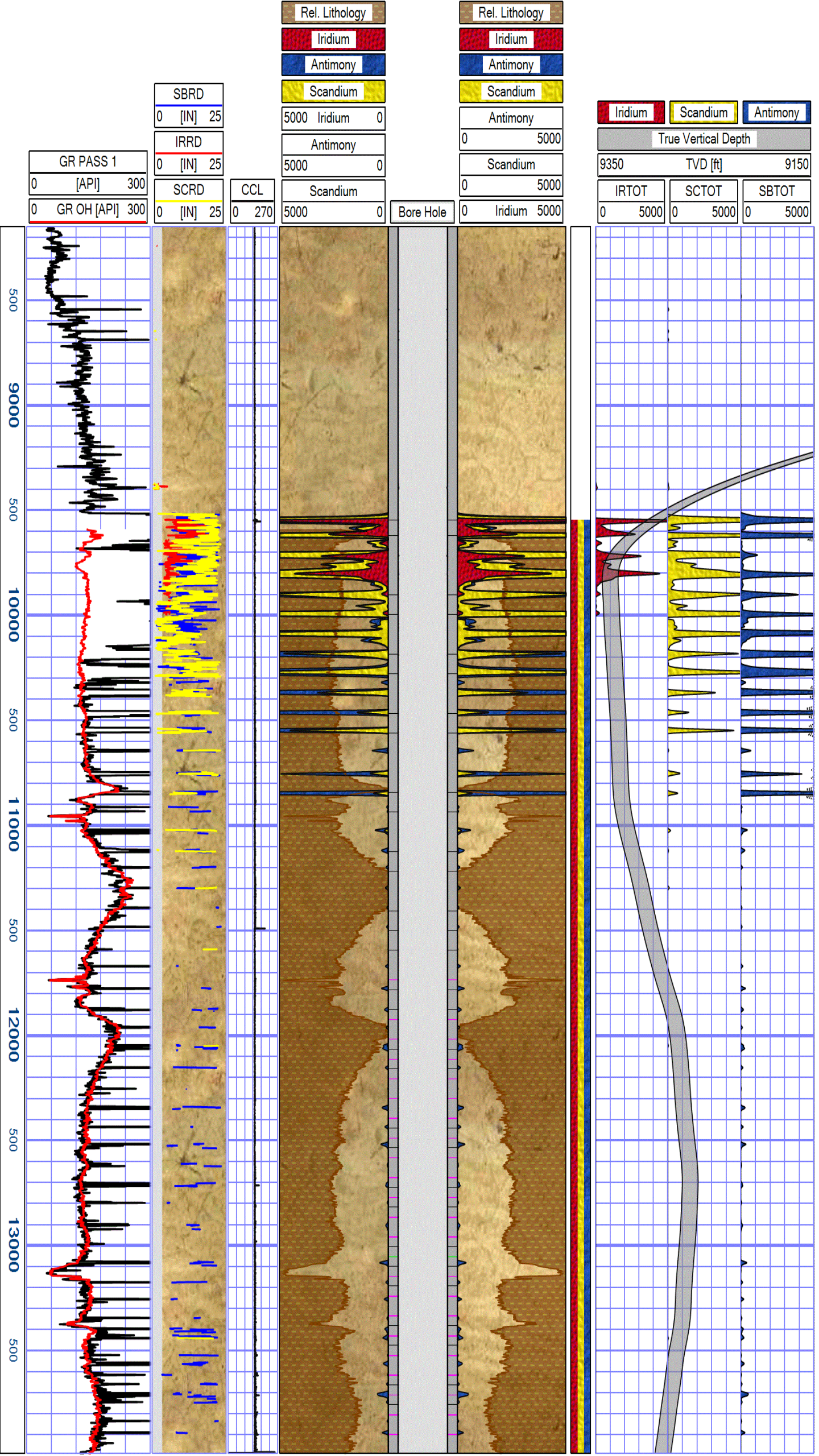
GR PASS 1
0 [API] 300
0 GR OH [API] 300
SBRD
0 [IN] 25
IRRD
0 [IN] 25
SCRD
0 [IN] 25
CCL
0 270
Rel. Lithology
Iridium
Antimony
Scandium
5000 Iridium 0
Antimony
5000 0
Scandium
5000 0
Bore Hole
Rel. Lithology
Iridium
Antimony
Scandium
Antimony
0 5000
Scandium
0 5000
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Iridium
Scandium
Antimony
True Vertical Depth
9350 TVD [ft] 9150
IRTOT
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SCTOT
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SBTOT
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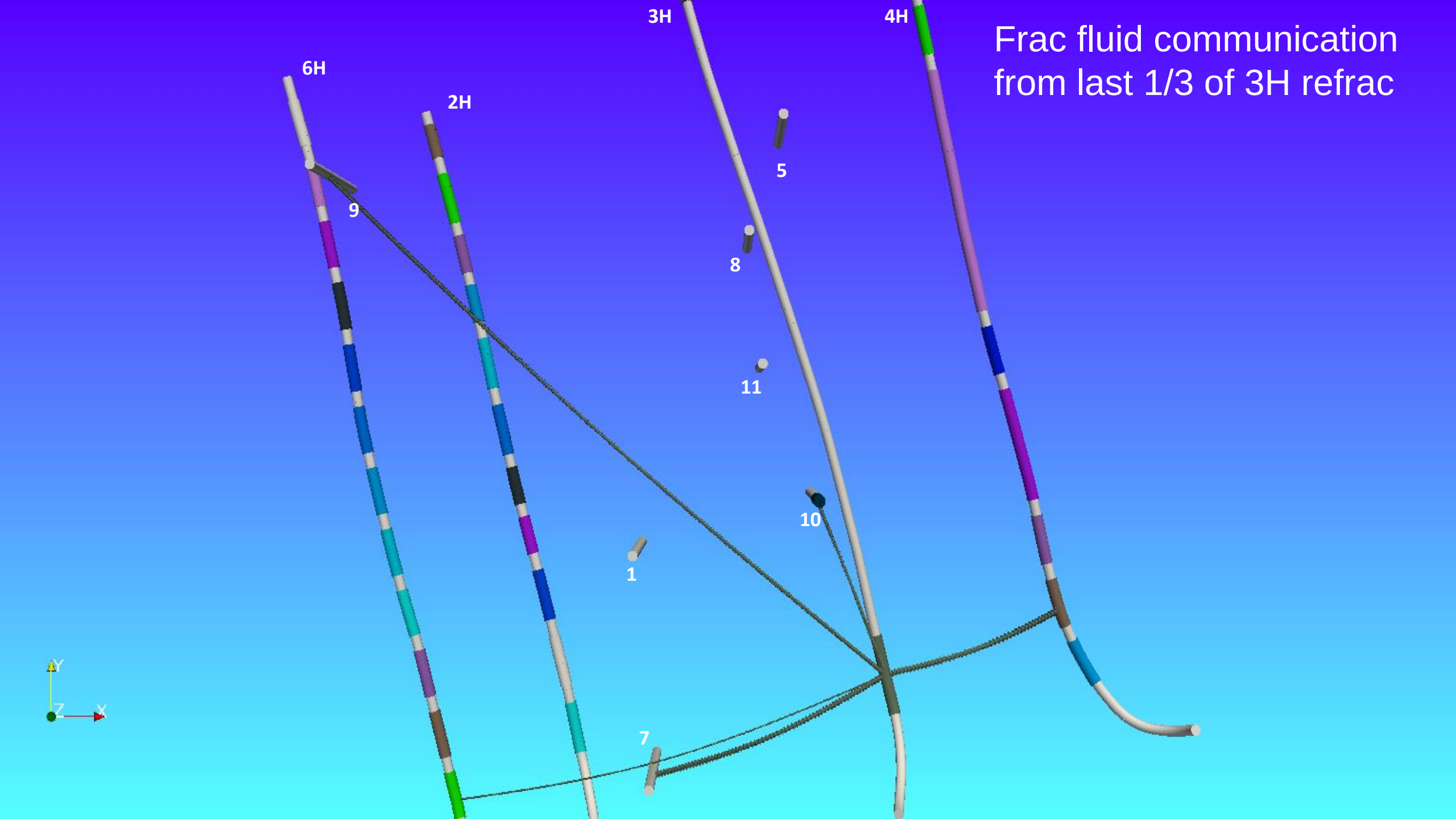
9000
10000
11000
12000
13000
500


Frac fluid communication from last 1/3 of 3H refrac
6H
2H
3H
4H
9
5
8
11
10
1
7
Y
Z
X

Refrac 2 - Conclusions/Observations

- Diagnostics confirm correlation between contacting new rock and productivity
- Mechanical isolation is the most definitive technique, but at the highest cost
- Liners w/gel blocking agents were the most widely-used in this study
- Horizontal wells with semi-permanent isolation exhibited the best coverage
- “Protection Refracs” are a viable option to mitigate interference whenever completing new wells in close proximity to an existing well
- Perforating and diversion techniques should be modified depending on the purpose (new rock, re-energizing existing well, restoring NWB conductivity

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SPE Paper 174851
Targeted Perforating in the Granite Wash Based on Traced Cement Spacer Leakoff

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Horizontal Perforation Selection

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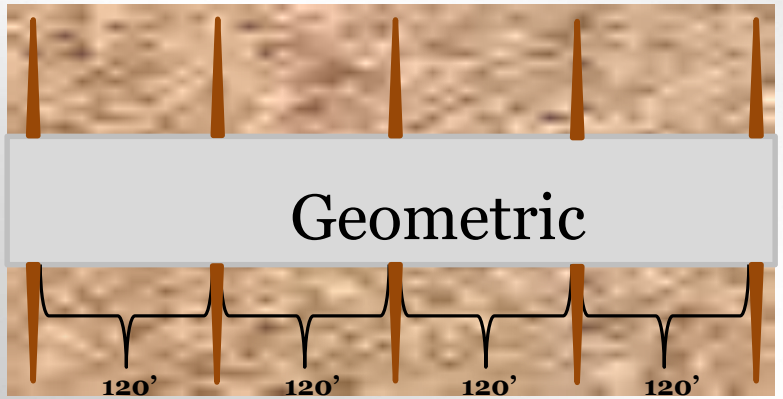
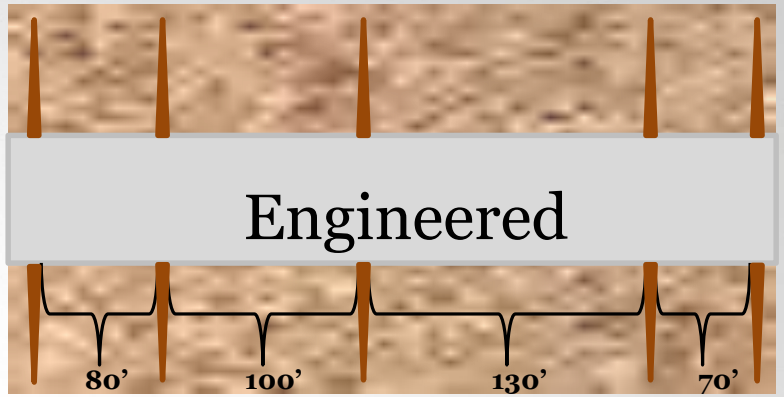
- Geometrically spaced
- Engineered
- Horizontal well log data limitations
- Complexity and predictability of reservoir





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Natural Fracture Contribution

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- Natural fractures in reservoir
  - Existing fracture networks can be conduits for hydrocarbons
  - Often more difficult to detect and characterize
  - Increase the contribution to wellbore when connected and propagated
- Image logs
  - Show geometry and petrophysical properties of the lateral
  - Identify fractures to target best places for perforations
- Leakoff mechanisms of natural fractures can be used to operators advantage

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Selective Perforating

Advantages

- Operational
  - Wells have fewer issues when similar rock is selectively perforated
  - Efficient operations since only “productive rock” is stimulated
- Production
  - Wells should have higher productivity with the best pay targeted

Disadvantages

- Operational
  - Appropriate tools are not always available, due to constraints or specific wellbore requirements
- Economics
  - Higher costs for specialty tools and wellbore preparation can be a factor

Pre-Frac Spacer Leakoff Log

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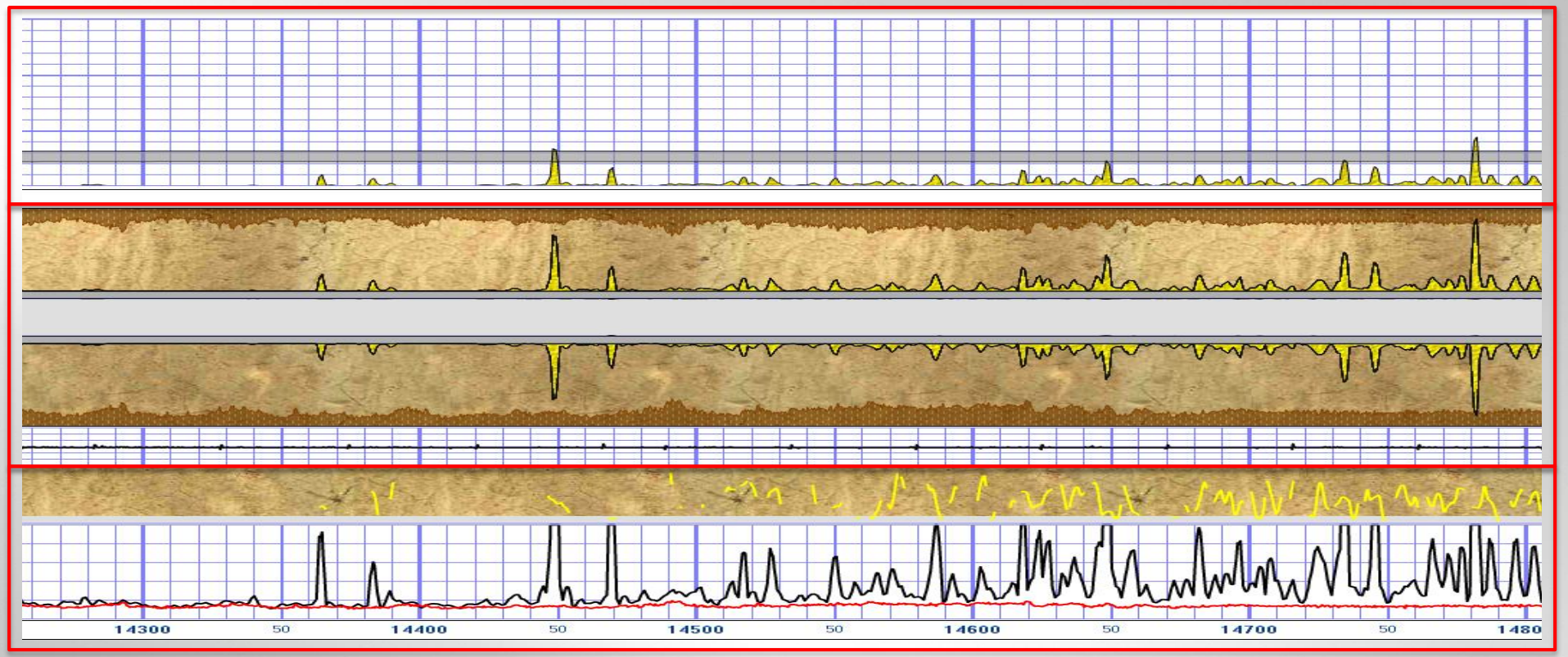

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Well M1H

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- Horizontal Marmaton well
- Proppant tracer injected into the cement spacer
  - Spectral gamma ray logged
  - Log evaluated
- 12 stages
  - First six stages geometrically spaced
  - Last six stages with engineered perforations based on the tracer leakoff
  - All stages were stimulated with the same stage design of fluid and proppant
- Stimulated stages were further traced to evaluate effective cluster stimulation
  - Spectral gamma ray logged again to confirm cluster coverage

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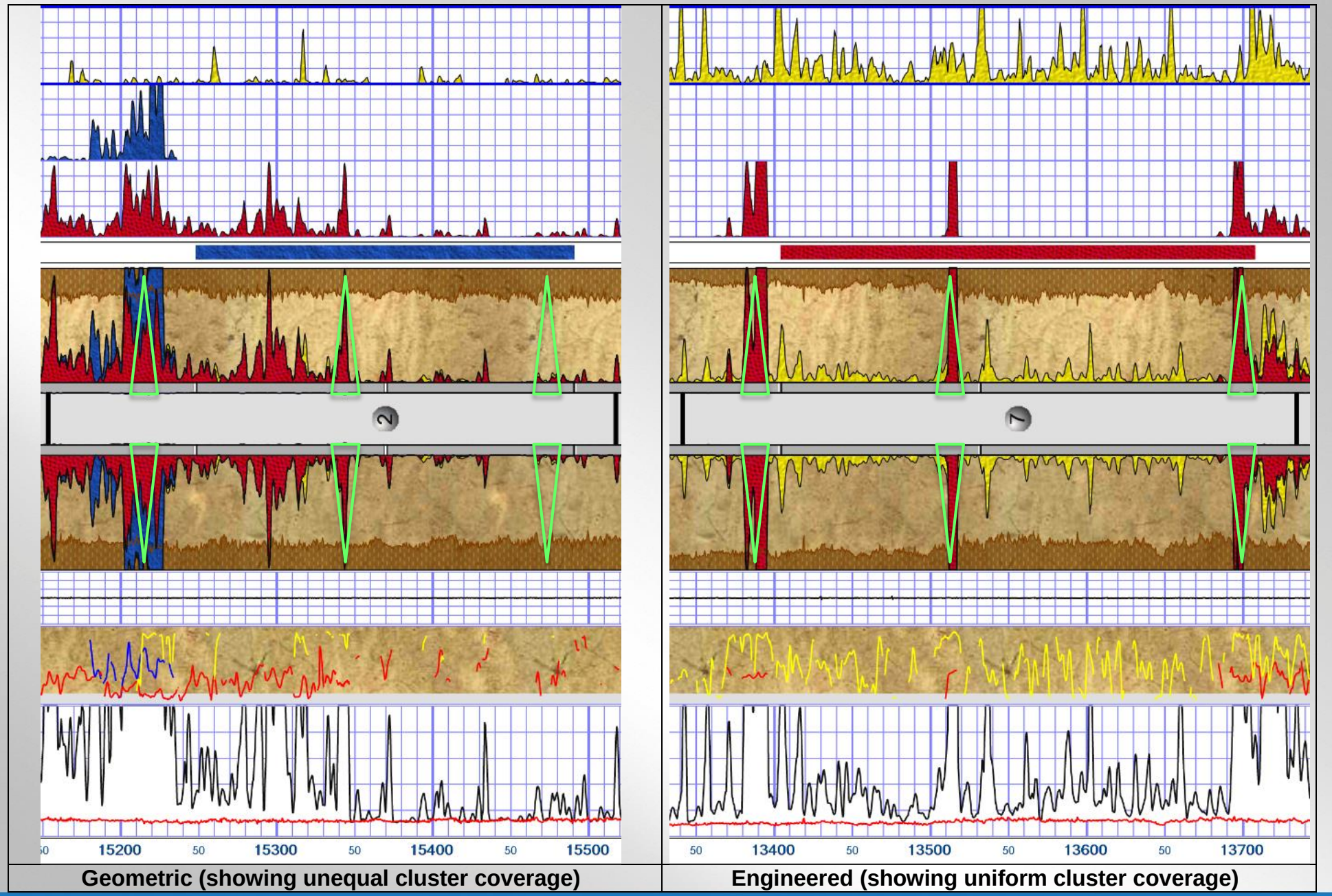
M1H Results



Geometric (showing unequal cluster coverage)

Engineered (showing uniform cluster coverage)

M1H Results

- All stages stimulated with the same design of fluid and proppant
- Stages 1-5 had a 73% cluster stimulated efficiency
  - The conventional 2/3 cluster stimulation was observed in most stages
- Stages 7-12 had an 89% cluster stimulated efficiency
  - All three clusters were stimulated in the majority of the stages
- Unstimulated selected clusters were evaluated on their leakoff signatures
  - Different signatures were observed, and success identified
  - Lessons learned were applied to the next series of selected perforations

CH1H & CH2H

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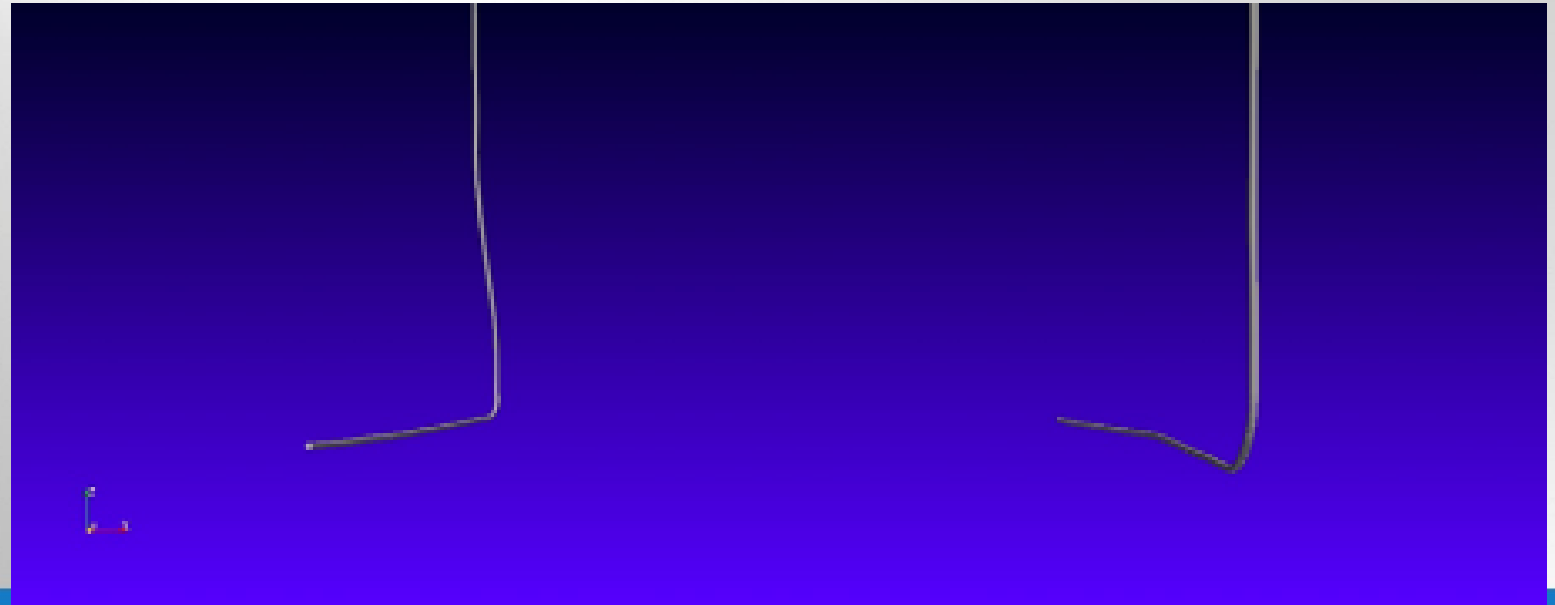
- Two wells were stimulated
- Checkerboard Formation
- Similar stage designs were planned
  - CH2H had one less stage than the CH1H due to lateral length
- All perforations were engineered
  - Lessons learned on leakoff signatures from the M1H were applied



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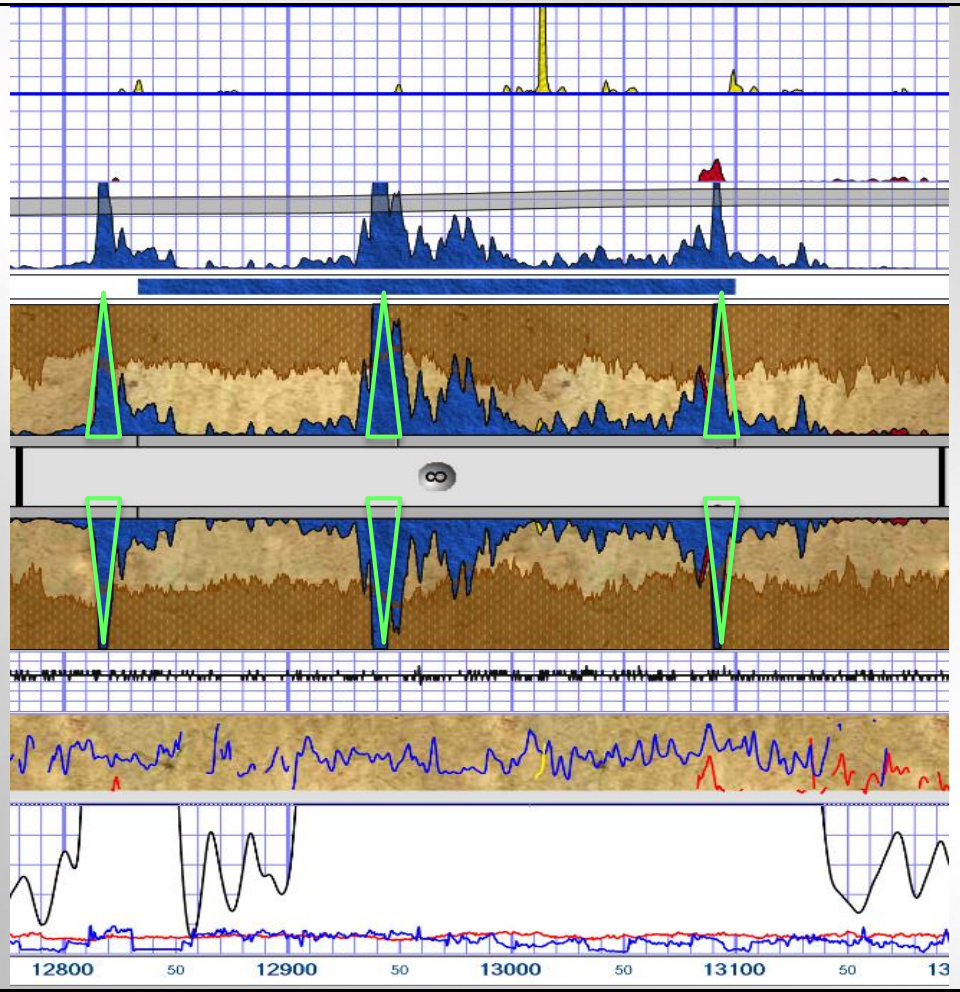
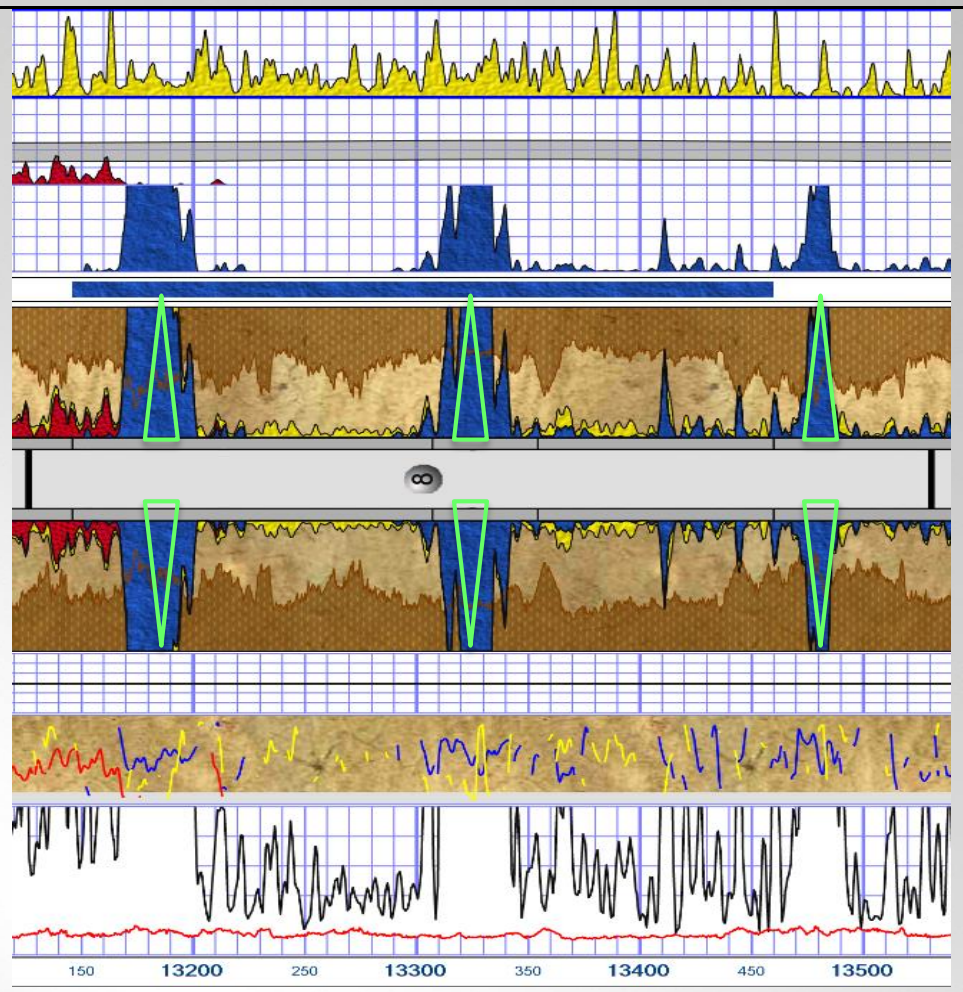
CH1H & CH2H



CH2H Stage 8



CH1H Stage 8

CH1H & CH2H Results

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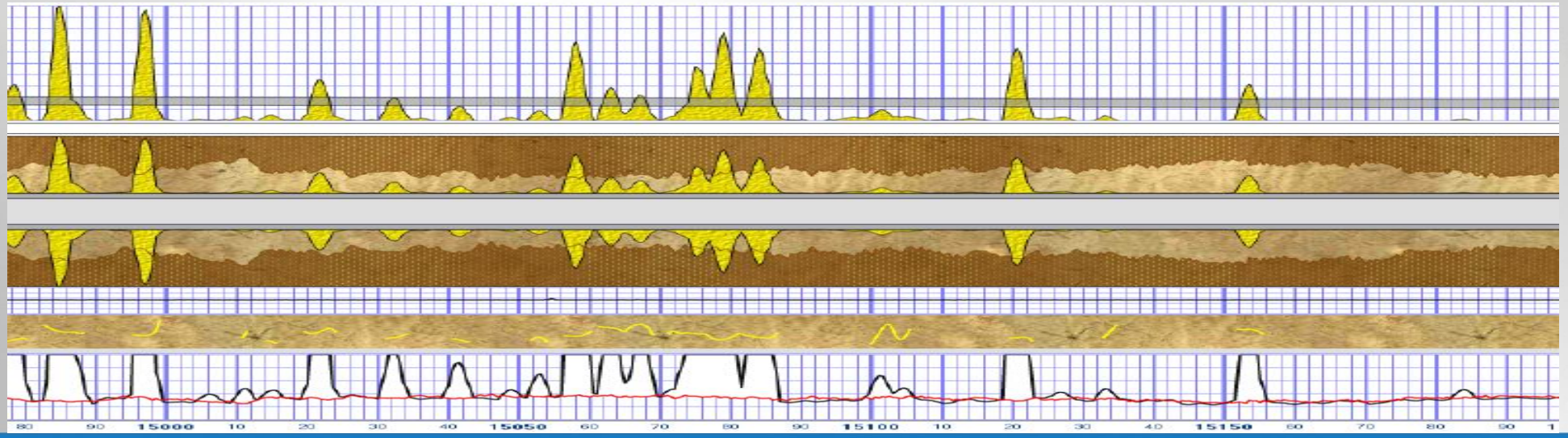
- An increase in effectively stimulated clusters over the M1H.
- Further evidence of the value of selected signatures.

Well Name	# clusters stimulated	% stimulated
CH1H	33/35	94%
CH2H	29/32	91%



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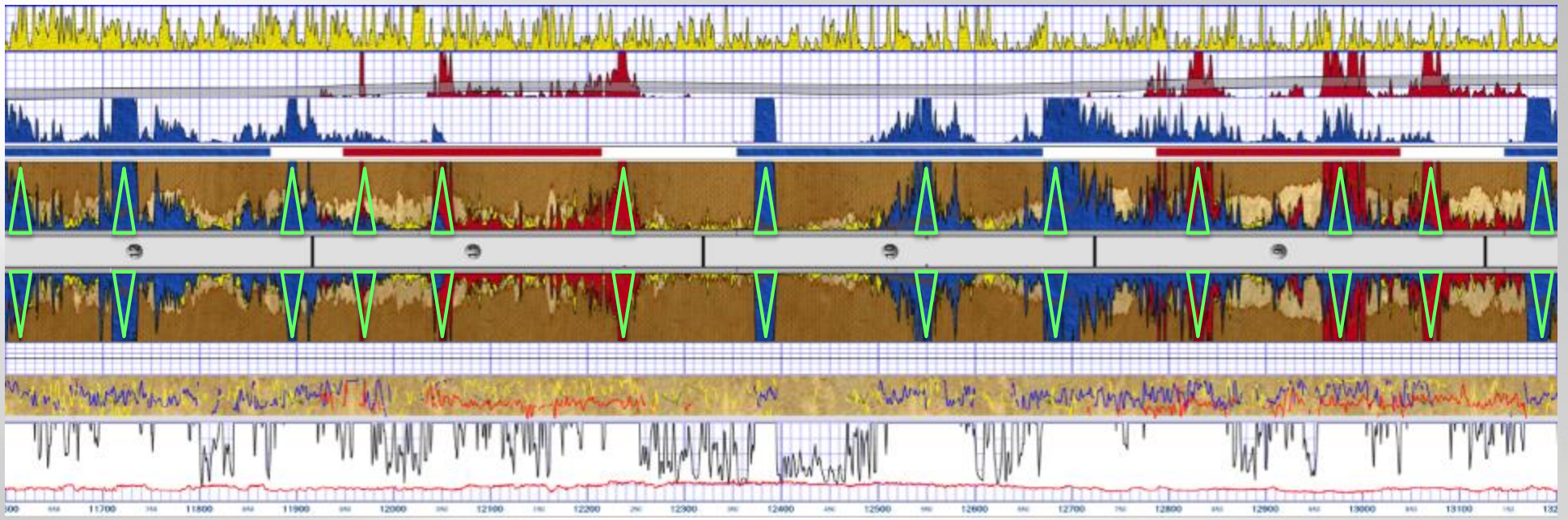
Spectral Gamma Ray Log: Post-Frac



CH1H

Results

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Well	Clusters Perforated	Clusters Stimulated	% Stimulated
M1H – Geometric	15	11	73%
M1H – Engineered	18	16	89%
CH1H	35	33	94%
CH2H	32	29	91%
CH3H	36	32	89%
G1H	30	27	90%
CH5H	90	80	89%

- Initial assumptions of ~66% cluster stimulation without selection trended correct.
- Immediate increase to 89% stimulation on first round of engineered perforations.
- As understanding of the cement spacer signatures increased, cluster treatment effectiveness increased to as high as 94%.

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Conclusions

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- The tracer in the cement spacer leaks off in a lateral drilled through the Granite Wash.
- A spectral gamma ray log can be used to record the leakoff signature along a horizontal well treated with cement spacer containing a tracer.
- It is possible for 90% of the perforation clusters to be effectively stimulated by utilizing this technique.
- More formations should be tested with the technique in order to determine its applicability.

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SPE Paper 174844
Reducing Costs and Optimizing Drilling and Completion Efficiencies in Unconventional Plays Using Completion Diagnostics

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Case A: 20 Stage Open Hole Sliding Sleeves

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- 20 Stages traced with frac fluid tracers
- After 162 hours of flowback, decision was made that intervention was required to produce all stages

Key				Normalized Chemical Frac Tracer Concentration, ppb																				
			Traced Segment	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1		
			Stim Date	Day 2	Day 2	Day 2	Day 2	Day 2	Day 2	Day 2	Day 2	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Totals	Avgs
			Traced Fluid vol (Gal)	175,938	168,378	172,200	179,088	164,934	168,462	180,978	174,510	171,864	194,334	179,340	177,240	171,234	171,234	174,216	178,248	195,930	189,546	187,446	182,532	3,557,652	177,883
			% Injected	4.9%	4.9%	4.7%	4.9%	4.7%	4.7%	5.1%	4.9%	5.1%	5.3%	5.1%	4.9%	5.1%	4.9%	4.9%	5.3%	4.9%	4.9%	5.1%	5.1%		
>200		Elapsed Sample Time (hr)	Sample Type	CFT T	CFT S	CFT R	CFT Q	CFT P	CFT O	CFT N	CFT M	CFT L	CFT K	CFT J	CFT I	CFT H	CFT G	CFT F	CFT E	CFT D	CFT C	CFT B	CFT A	CFT Total ppb	Calc Chlorides Total
150 to 200	1	0.00	Water (Produced)	198.8	56.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	254.8	127,384
100 to 150	2	12.02	Water (Produced)	90.1	26.5	41.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	157.8	148,030
70 to 100	3	36.02	Water (Produced)	94.9	30.1	26.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	151.6	141,125
50 to 70	4	60.02	Water (Produced)	77.4	22.6	23.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	123.6	151,554
35 to 50	5	90.00	Water (Produced)	54.6	13.1	14.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	82.2	138,845
25 to 35	6	114.00	Water (Produced)	43.9	10.3	12.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.1	135,508
17 to 25	7	162.00	Water (Produced)	18.7	6.3	7.7	16.9	15.4	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.7	79,180
12 to 17	8	210.00	Water (Produced)	7.8	2.1	2.5	3.6	0.0	0.0	0.6	2.8	3.5	9.0	4.0	1.1	1.1	6.8	0.9	0.0	0.0	0.0	8.3	6.3	60.3	98,538
8 to 12	9	258.00	Water (Produced)	9.1	3.1	4.2	4.1	1.8	0.0	0.5	2.1	2.5	6.7	3.5	1.0	0.5	4.8	0.9	0.0	0.0	0.0	6.0	5.1	55.9	111,003
5 to 8	10	306.00	Water (Produced)	9.1	3.4	4.3	4.2	3.1	0.0	0.5	2.1	2.3	6.2	3.4	0.8	0.7	4.0	0.9	0.0	0.0	0.0	5.5	4.8	55.4	117,977
3 to 5	11	354.00	Water (Produced)	8.9	3.4	4.4	3.2	2.1	0.0	0.4	1.8	1.9	5.4	2.9	0.6	1.1	3.8	0.9	0.0	0.0	0.0	5.2	4.6	50.5	110,968
2 to 3	12	428.50	Water (Produced)	8.5	2.9	4.5	5.0	4.9	0.8	0.9	2.5	2.3	6.6	3.7	0.6	0.6	3.0	0.8	0.3	0.4	0.6	4.3	4.2	57.4	73,610
1 to 2	13	476.25	Water (Produced)	8.0	2.6	3.9	4.6	4.5	0.8	0.7	1.8	2.2	5.9	3.1	0.5	0.4	2.7	0.7	0.3	0.3	0.4	3.6	3.6	50.8	95,591
0.05 to 1	14	524.25	Water (Produced)	6.5	2.1	3.2	5.1	4.9	1.1	0.8	1.8	2.5	5.5	2.9	0.7	0.4	2.3	0.7	0.3	0.4	0.4	2.9	3.3	47.5	111,990
	15	572.25	Water (Produced)	6.3	1.8	2.9	5.2	4.7	0.9	0.7	1.5	2.3	5.3	2.6	0.6	0.3	2.2	0.6	0.3	0.3	0.4	2.6	3.0	44.7	111,327
	16	620.25	Water (Produced)	7.5	1.8	3.2	4.8	4.4	0.9	0.8	1.5	1.9	4.8	2.3	0.5	0.0	1.5	0.6	0.3	0.3	0.4	2.5	2.9	42.9	106,856

Core Lab

Case B: 20 Stage Open Hole Sliding Sleeves

- 20 Stages traced with oil tracers
- No intervention was required due to confirmation of oil contribution from every stage

	Normalized Oil Frac Tracer % Contribution																			
Stages	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	
Elapsed Sample Time (hr)	OFT T	OFT S	OFT R	OFT Q	OFT P	OFT O	OFT N	OFT M	OFT L	OFT K	OFT J	OFT I	OFT H	OFT G	OFT F	OFT E	OFT D	OFT C	OFT B	OFT A	OFT Total ppb
0.00	2.3	0.6	2.3	4.8	6.5	5.7	4.7	1.1	6.0	24.6	9.7	11.6	10.6	1.7	2.5	2.1	0.8	1.3	0.5	0.9	4,158
12.00	1.9	0.6	2.1	4.9	6.8	6.1	5.7	1.4	6.0	19.4	8.2	12.3	12.0	2.9	4.5	2.7	0.6	0.9	0.3	0.7	3,767
36.00	1.9	0.6	2.6	5.3	6.8	6.1	5.5	1.4	5.1	16.6	7.6	10.4	11.2	4.2	6.5	5.9	0.6	0.8	0.2	0.7	2,619
60.00	2.2	0.7	3.3	6.0	7.5	6.6	5.7	1.4	4.9	13.9	7.6	9.6	10.2	4.1	6.8	7.0	0.8	0.8	0.3	0.7	2,424
96.00	1.9	0.8	3.1	7.6	8.8	7.9	5.6	0.8	5.0	9.2	8.0	9.3	10.2	3.4	5.6	11.0	1.0	0.3	0.1	0.2	1,523
144.00	1.9	1.0	6.2	8.4	8.4	7.5	5.6	0.8	4.6	7.4	8.6	7.6	11.4	2.5	3.7	11.8	2.0	0.4	0.1	0.2	1,006
192.00	2.4	1.1	5.9	8.0	9.9	8.4	5.5	0.7	4.9	7.9	8.0	7.4	10.6	2.1	3.4	10.9	2.2	0.3	0.2	0.2	1,011
262.00	2.0	2.3	6.3	8.0	11.7	9.6	6.0	1.4	4.8	5.8	4.4	5.1	6.3	3.2	3.9	12.7	3.0	1.5	1.4	0.7	629
312.00	2.1	2.3	7.4	9.7	13.7	11.3	5.5	1.1	3.9	4.8	3.8	5.0	5.1	3.2	3.7	11.0	2.7	1.4	1.5	0.7	578
360.00	2.3	3.0	10.0	9.7	11.2	9.4	5.3	1.1	3.6	4.1	3.9	4.9	4.7	3.0	3.3	11.4	3.1	2.5	2.5	1.1	480
408.00	3.4	4.7	10.0	7.5	9.5	8.0	5.1	1.1	3.8	4.2	3.5	4.7	4.5	2.9	3.1	10.6	4.1	3.7	3.7	1.8	385
456.00	2.5	4.0	8.8	7.6	10.3	8.5	4.8	1.1	3.8	5.0	3.8	4.5	4.3	2.9	3.2	9.6	4.6	4.2	4.3	2.3	350
2776.00	8.3	6.7	8.8	5.3	9.4	7.9	4.5	2.0	3.9	6.4	1.8	8.7	4.4	0.3	1.2	8.8	5.3	1.8	2.1	2.4	233
2824.00	6.1	7.2	9.0	5.0	8.0	6.9	4.9	2.2	3.2	6.4	1.9	9.9	5.2	0.7	0.7	11.0	6.1	1.6	2.0	1.9	264
2848.00	6.9	6.8	9.8	5.5	10.0	8.7	4.1	1.9	4.1	5.8	2.6	8.4	4.2	0.8	1.3	6.6	5.5	1.9	2.4	2.7	202
Time Weighted Avg	7.3	6.0	8.5	5.7	9.5	8.0	4.7	1.9	4.0	6.6	2.4	8.3	4.9	0.7	1.6	9.1	4.8	1.8	2.0	2.2	356
Trend																					

Case C: 20 Stage Multicluster Cemented Sleeves

ProTechnics

- Well 2: Gas Traced
- 15 segments traced over 20 stages
- Toe segments lagging through sampling period until seats are milled

Key
>75
55 to 75
40 to 55
25 to 40
15 to 25
10 to 15
7.5 to 10
5 to 7.5
2.5 to 5
1 to 2.5
0.75 to 1
0.5 to 0.75
0.2 to 0.5
0.1 to 0.2
0.05 to 0.1

			Normalized Gas Concentration, ppb															
		Traced Segment	20	19	18	17	16-15	14-13	12-11	10-9	8-7	6	5	4	3	2	1	
		Stim Date	Day 2	Day 2	Day 2	Day 2	Day 2	Day 2	Day 2	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Day 1	Totals
		% Injected	5.0%	5.0%	5.0%	5.0%	10.0%	10.0%	10.0%	10.0%	10.0%	5.0%	5.0%	5.0%	5.0%	5.0%	5.0%	
	Elapsed Sample Time (hr)	Sample Type	GFT O	GFT N	GFT M	GFT L	GFT K	GFT J	GFT I	GFT H	GFT G	GFT F	GFT E	GFT D	GFT C	GFT B	GFT A	GFT Total ppb
1	0.25	Gas (Produced)	12.0	48.3	31.6	12.7	3.2	1.5	4.7	1.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0	115
2	7.00	Gas (Produced)	15.5	66.7	46.1	17.8	4.7	2.3	7.4	1.6	0.0	0.0	0.0	0.2	0.2	0.0	0.0	162
3	20.00	Gas (Produced)	13.9	57.2	42.6	16.2	4.8	2.5	7.4	1.7	0.0	0.0	0.0	0.3	0.2	0.0	0.3	147
4	44.00	Gas (Produced)	13.0	53.9	40.0	15.2	4.5	2.3	6.9	1.5	0.0	0.0	0.0	0.2	0.2	0.0	0.1	138
5	73.00	Gas (Produced)	14.3	59.2	43.6	16.6	5.0	2.5	7.7	1.8	0.0	0.0	0.0	0.2	0.3	0.0	0.5	152
6	97.00	Gas (Produced)	32.6	57.5	43.1	18.2	5.2	4.5	7.2	3.0	0.0	1.3	0.0	1.5	1.4	0.0	6.8	182
7	146.00	Gas (Produced)	14.2	52.0	38.2	14.5	4.2	2.3	6.3	1.6	0.0	0.1	0.0	0.3	0.3	0.0	0.8	135
8	189.00	Gas (Produced)	10.5	53.3	36.4	14.3	3.5	1.6	6.8	1.5	0.0	0.0	0.0	0.2	0.2	0.0	0.2	129
9	229.50	Gas (Produced)	5.3	30.5	23.3	9.8	3.7	2.1	5.3	1.4	0.0	0.0	0.0	0.1	0.1	0.0	0.0	81
10	286.00	Gas (Produced)	3.4	19.3	15.3	7.3	3.3	1.9	4.0	1.2	0.0	0.0	0.0	0.1	0.1	0.0	0.0	56
11	332.50	Gas (Produced)	4.0	22.3	17.5	9.0	4.2	2.5	4.4	1.5	0.0	0.0	0.0	0.1	0.2	0.0	0.1	66
12	381.00	Gas (Produced)	4.1	22.8	16.6	9.0	4.5	2.7	4.7	1.8	0.0	0.0	0.0	0.1	0.3	0.0	0.3	67
13	433.00	Gas (Produced)	3.3	19.1	14.2	8.1	4.2	2.5	4.3	1.6	0.2	0.0	0.0	0.1	0.2	0.0	0.1	58
14	477.50	Gas (Produced)	2.8	15.5	12.2	7.4	3.9	2.4	3.9	1.5	0.2	0.0	0.0	0.1	0.2	0.0	0.2	50
15	668.00	Gas (Produced)	0.5	2.5	3.2	2.2	1.2	0.7	1.5	1.7	3.2	0.0	0.3	1.0	0.7	6.9	2.6	28
16	836.50	Gas (Produced)	0.5	1.9	2.2	1.6	1.1	0.6	0.8	0.9	1.4	0.0	0.2	0.5	0.4	3.5	1.1	17
17	1010.00	Gas (Produced)	0.3	1.7	1.8	1.2	0.9	0.6	0.4	0.4	1.0	0.0	0.1	0.2	0.2	2.5	0.7	12
18	1178.50	Gas (Produced)	0.3	1.3	1.3	0.9	0.6	0.4	0.3	0.3	0.7	0.0	0.1	0.2	0.2	1.7	0.6	9
19	1346.00	Gas (Produced)	0.2	1.1	1.1	0.7	0.6	0.4	0.2	0.3	0.7	0.0	0.0	0.1	0.1	1.5	0.4	7
20	1516.00	Gas (Produced)	0.2	1.2	1.1	0.7	0.5	0.4	0.2	0.2	0.6	0.0	0.0	0.1	0.1	1.6	0.4	7
		Time Weighted Avg. ppb	2.9	12.1	9.4	4.4	1.9	1.1	2.1	1.0	0.9	0.0	0.1	0.3	0.3	2.1	0.9	39.4
		% total ppb from Stage	7.4%	30.8%	23.8%	11.1%	4.7%	2.8%	5.3%	2.4%	2.3%	0.1%	0.2%	0.8%	0.7%	5.2%	2.2%	100.0%
		% total ppb @ last sample	2.7%	16.0%	15.4%	9.3%	7.1%	5.6%	2.3%	3.0%	7.9%	0.0%	0.0%	1.6%	1.8%	21.3%	5.9%	

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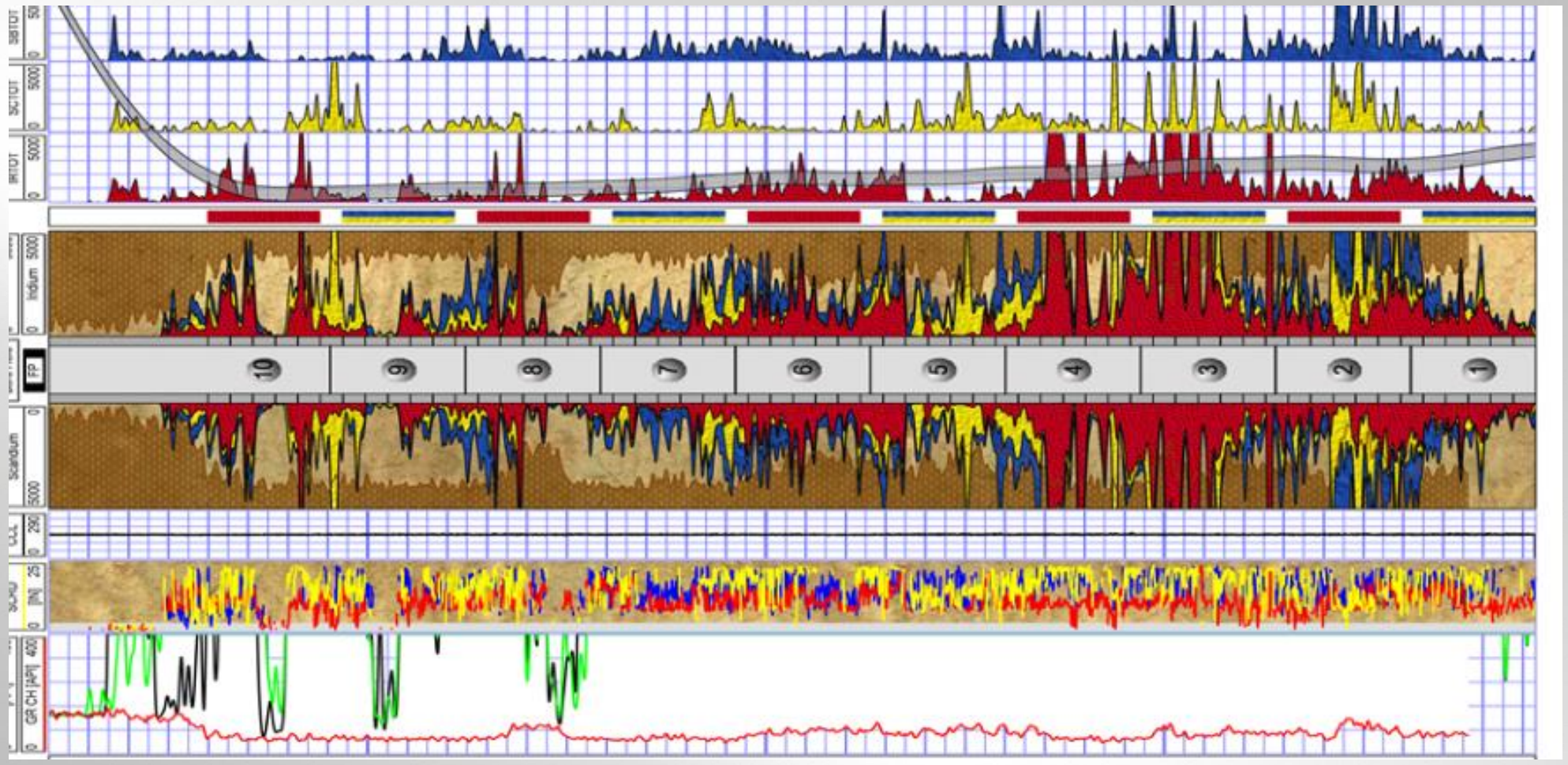
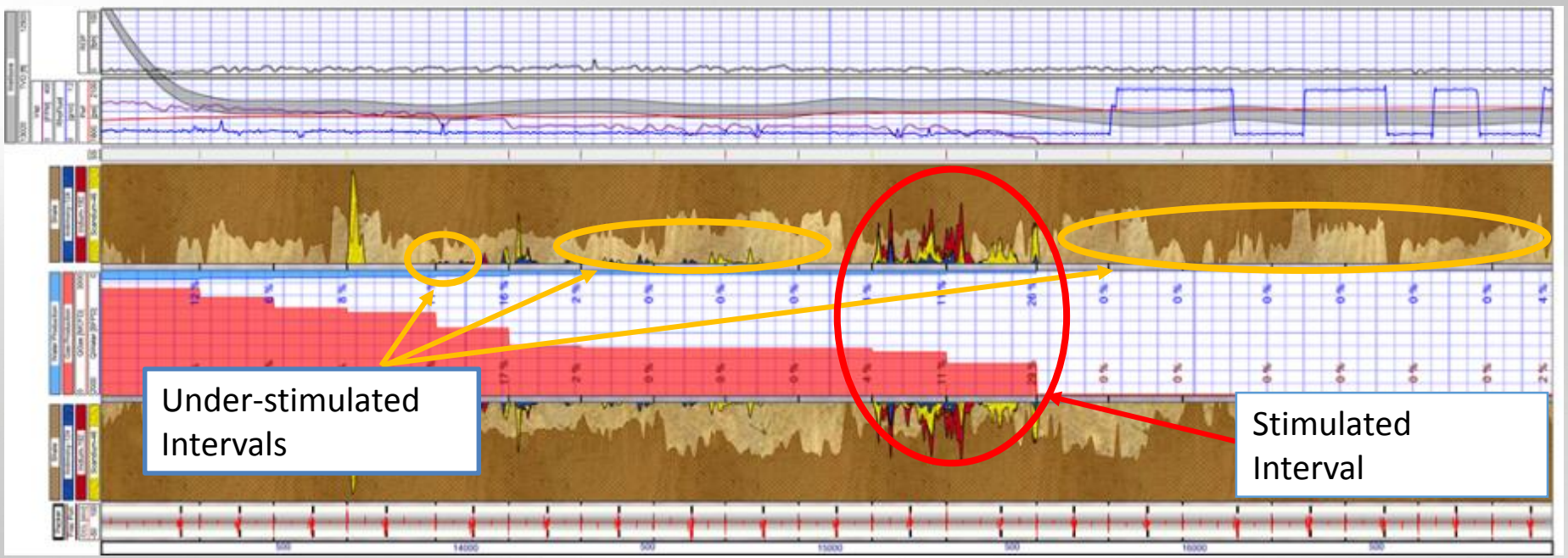
Case A: Treatment of Large Interval Through the Use of Diversion



Case B: Change of Completion Type



Conclusions

- Flow assurance in horizontal wells can be evaluated with the use of water and hydrocarbon tracers
- Proppant tracers can be applied to ensure the functionality of newly implemented drilling and completion practices
- Effective diversion was demonstrated by proppant tracing to mitigate cement isolation failures
- New and existing completion practices can be implemented and diagnostically tested to ensure reserves are accessed per design
- Interwell communication studies can help find an optimum well spacing

SPE Hydraulic Fracturing Technology Conference

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Determining the Effectiveness of Isolation Techniques Using Completion Diagnostics and Production Analysis

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Society of Petroleum Engineers
Annual Technical Conference and Exhibition
26–28 September 2016
DUBAI WORLD TRADE CENTRE
Dubai, UAE

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Evaluation of Completion Practices in the STACK Using Completion Diagnostics and Production Analysis

Scott Van Sickle, DJ Snyder, Chad Senters

SPE International
Society of Petroleum Engineers

Background

- Investigate isolation effectiveness
- Identify possible failure mechanisms
- Present the trends of the diagnostics data
- Validate assumption “better isolation = better production”

Outline

- Introduction and Area Overviews
- Introduction to Isolation Methods
- Potential Failure Mechanisms
- Examples
- Basin Specific Results
- Conclusions
- Future Work
- Questions

Introduction to Isolation Methods

ProTechnics

Types of Isolation/Diversion Methods

- Non-cased
- Slotted Liners
  - Sand Plugs
  - Ball Sealers
  - Fiber
- Cemented Plug and Perf

Common Methods Today

- Open Hole Packers
  - Hydro-Mechanical
  - Swellable
- Uncemented Plug and Perf

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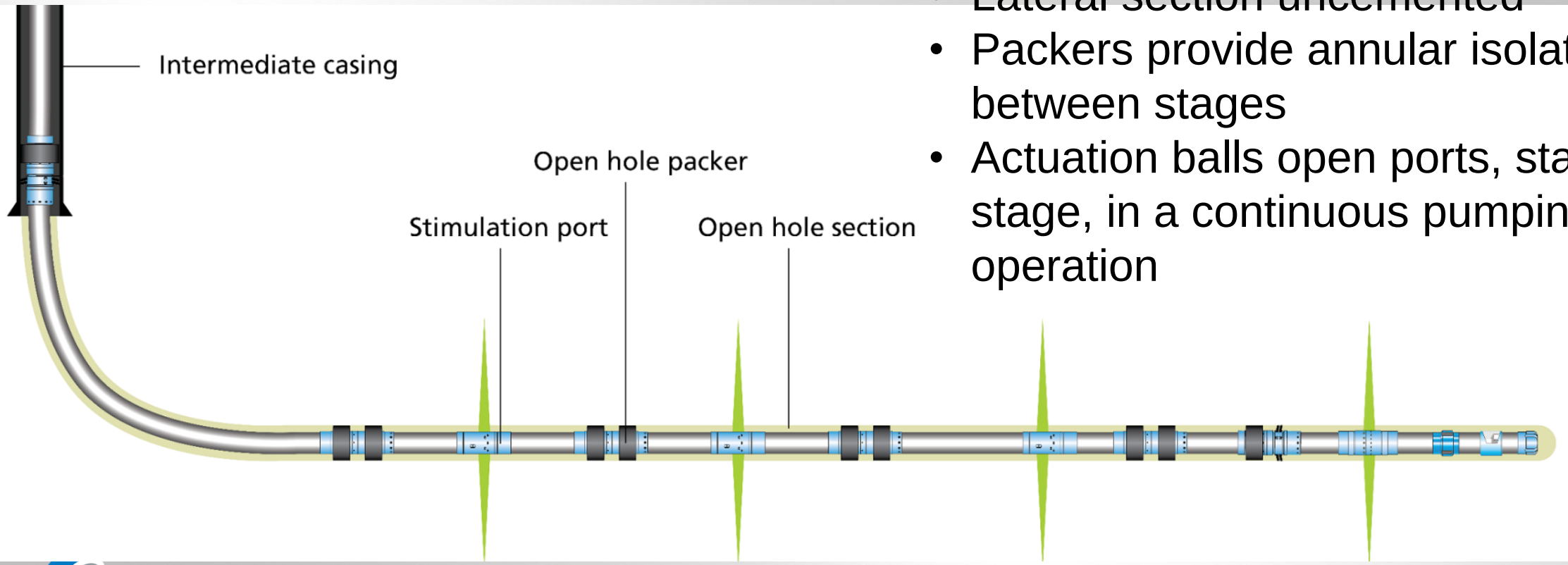
Typical Uncemented Completion System

ProTechnics



- Ports and packers run into the well as part of liner
- Lateral section uncemented
- Packers provide annular isolation between stages
- Actuation balls open ports, stage by stage, in a continuous pumping operation

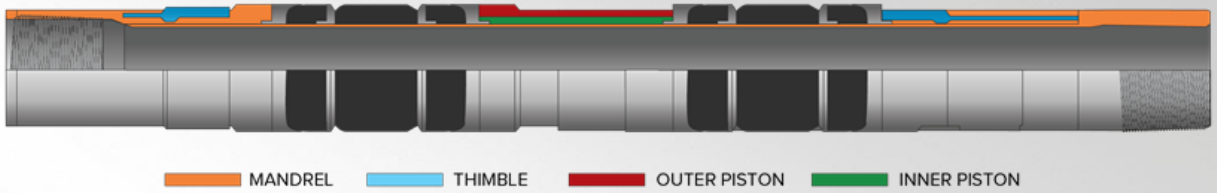
Single Element Hydro-Mechanical Packer

ProTechnics

- Made with a single element or single piston

Dual Element Hydro-Mechanical Packer

- Opposing pistons set by hydraulic pressure in liner to compress elements
- Redundancy – 2 independent sealing points against wellbore



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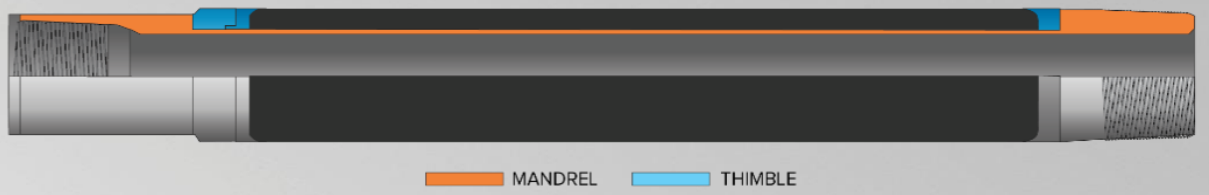
Swellable Element Packer

ProTechnics

- Not hydraulically set
- Expands in the presence of water/oil
- Rubber degrades and expands
- Longer than HMSPs (5 to 30 ft)



Fracturing Port

- Outer housing with inner sliding sleeve
- Ball seat attached to sliding sleeve
- Shear pins break and sliding sleeve opens port to access formation

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Potential Failure Mechanisms

ProTechnics

Annular Isolation

- Excessive Differential Pressure
- Thermal Contraction
- Pressure Cycling Fatigue
- Fracture Initiation at Packer

Internal Isolation

- Ball/Seat Failure
  - Ball Tolerances
  - Working Limits
  - Erosion
  - Port Functionality
    - Prematurely Open
    - Dual Ball seats
- Plug Failures
  - Ball (when applicable)
  - Plug not set
  - Erosion

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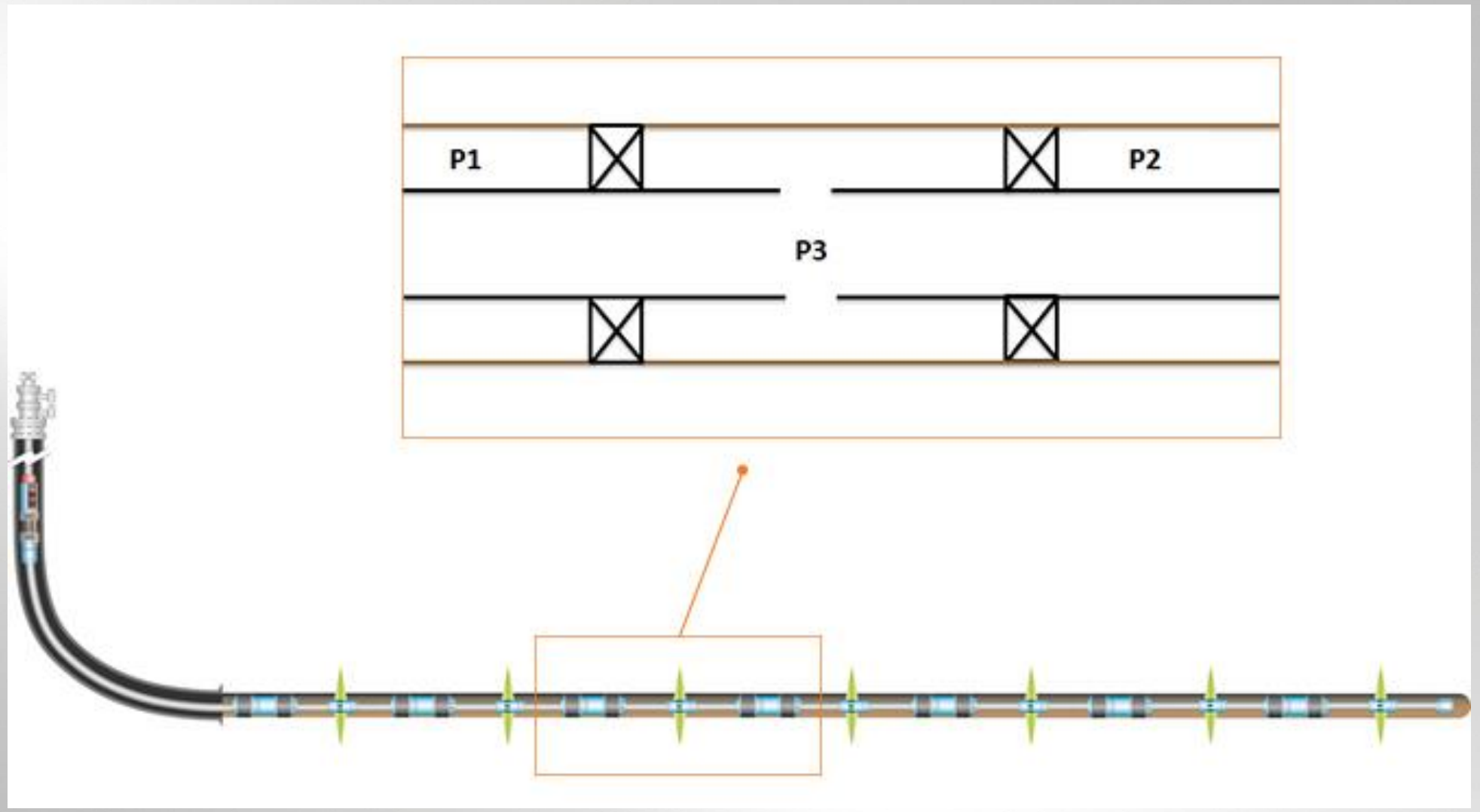
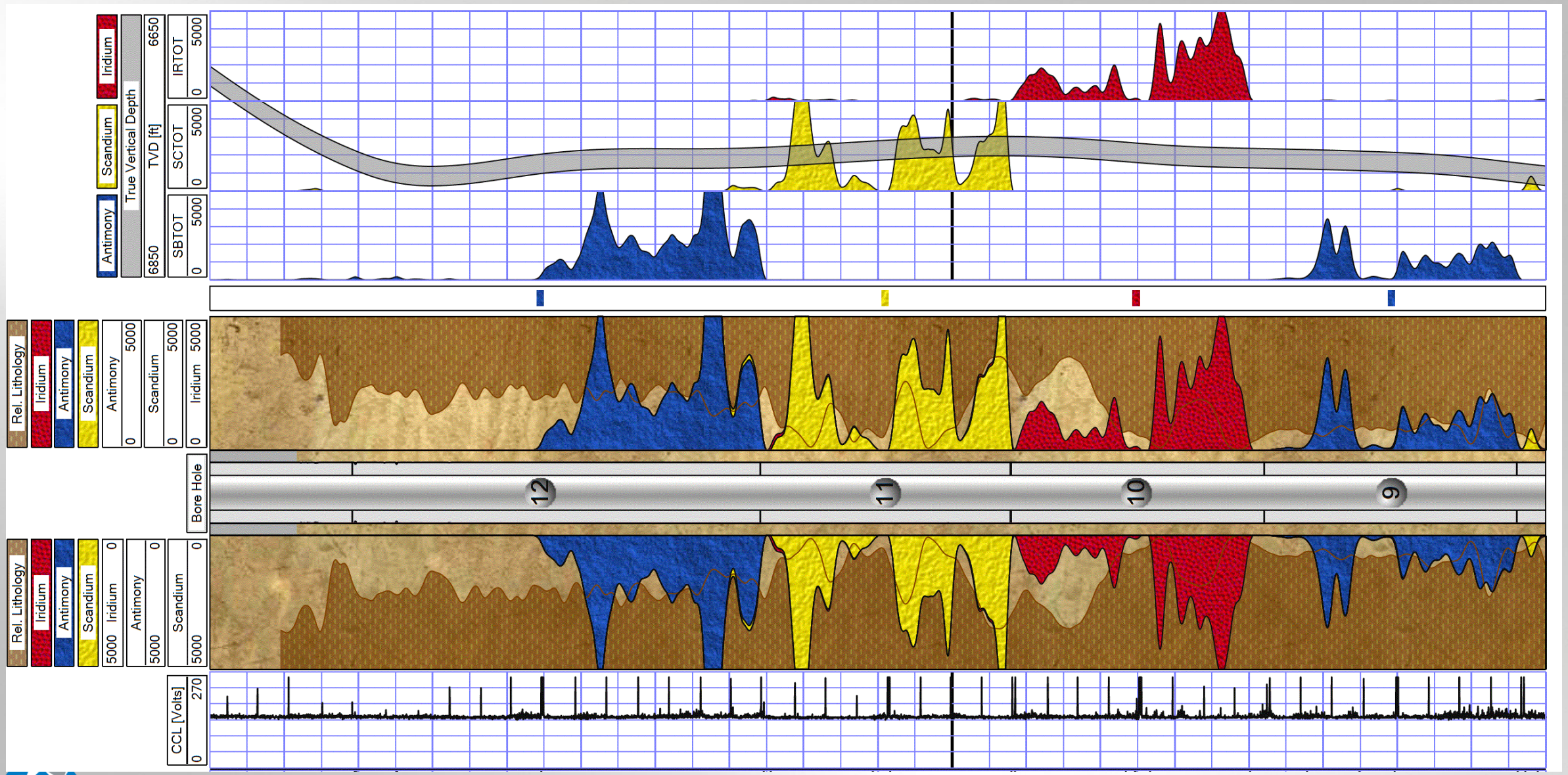
Potential Failure Mechanisms



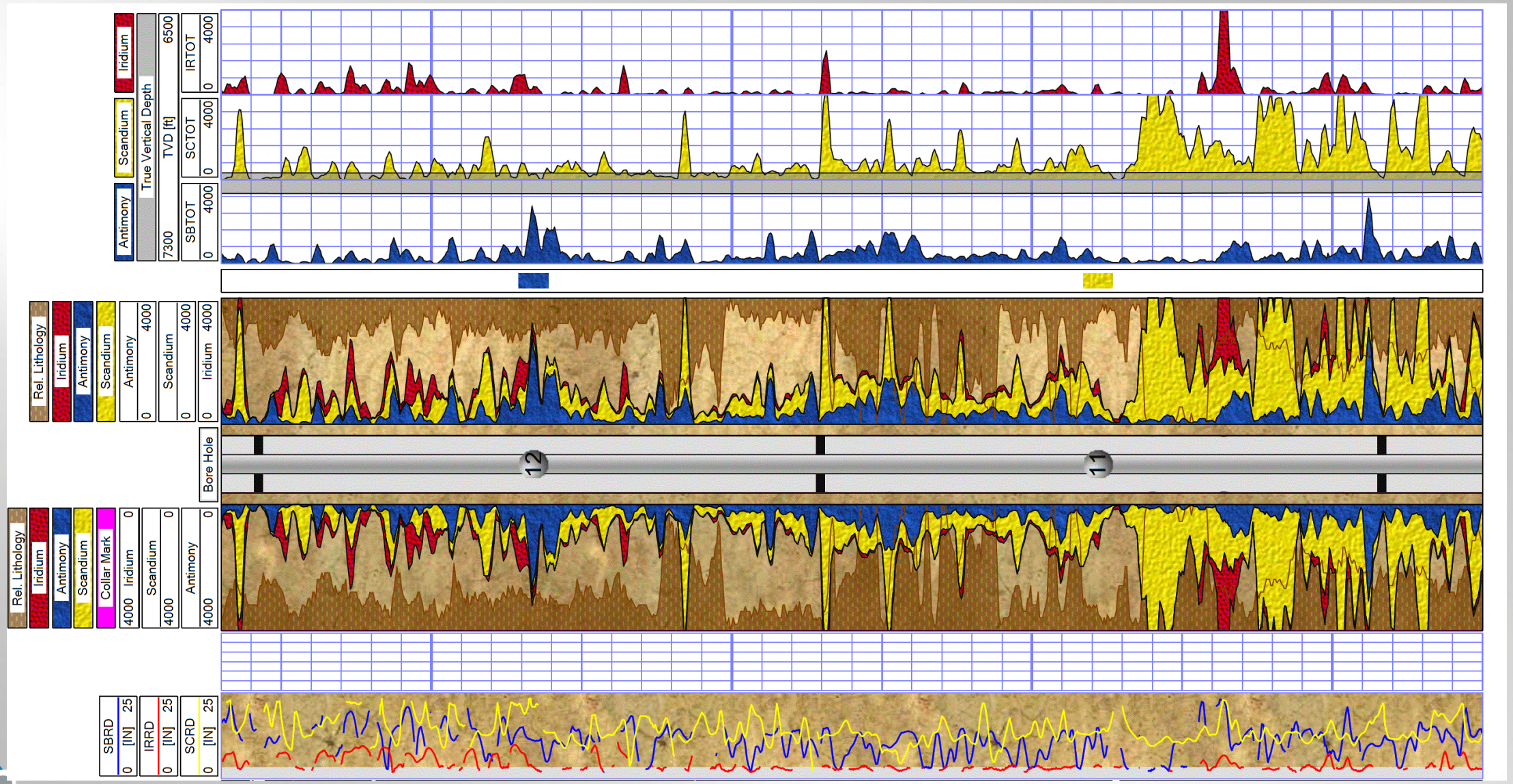
Example 1- Effective Packer Isolation

ProTechnics



Example 2 – Poor Packer Isolation

ProTechnics



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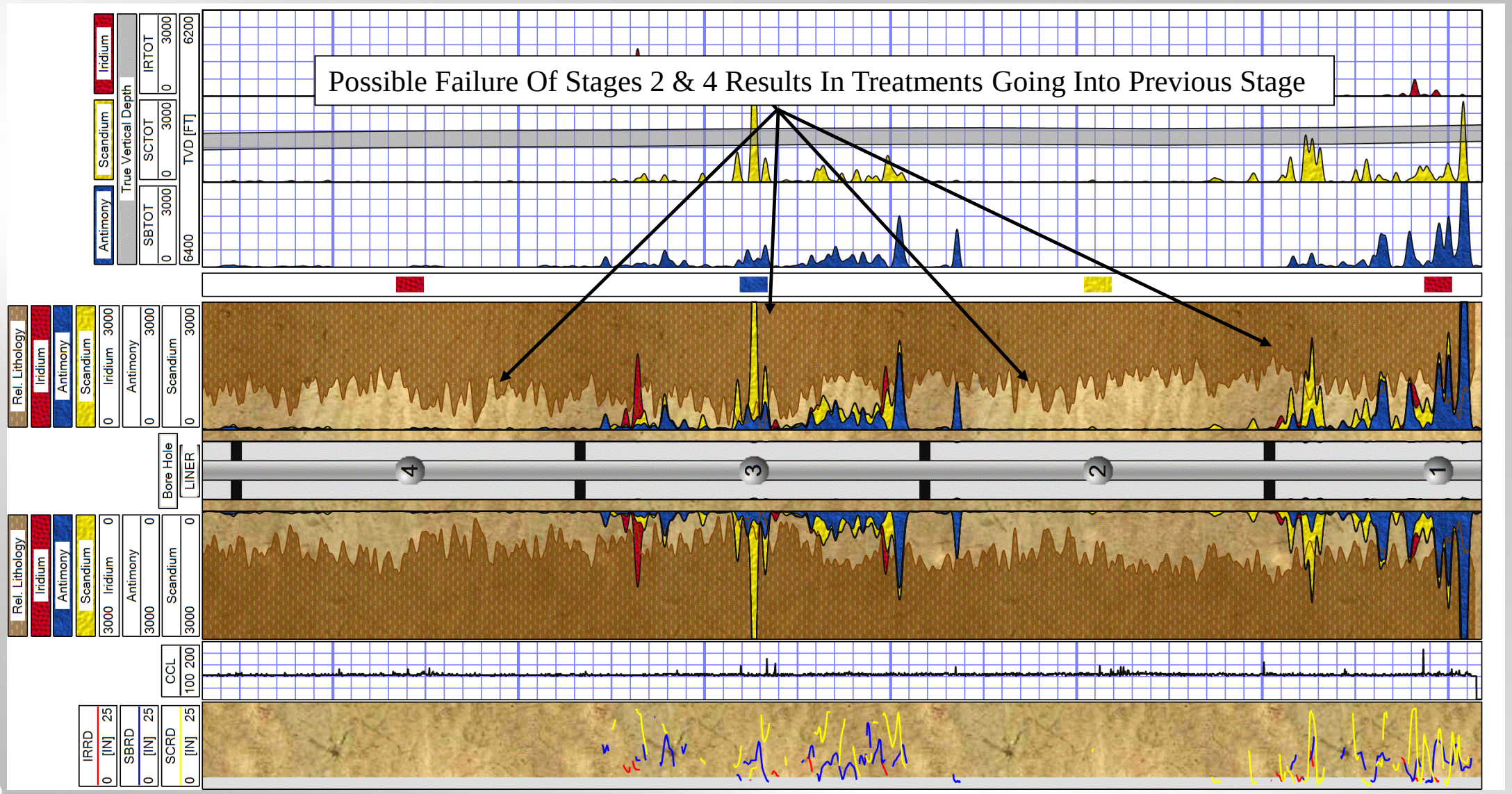
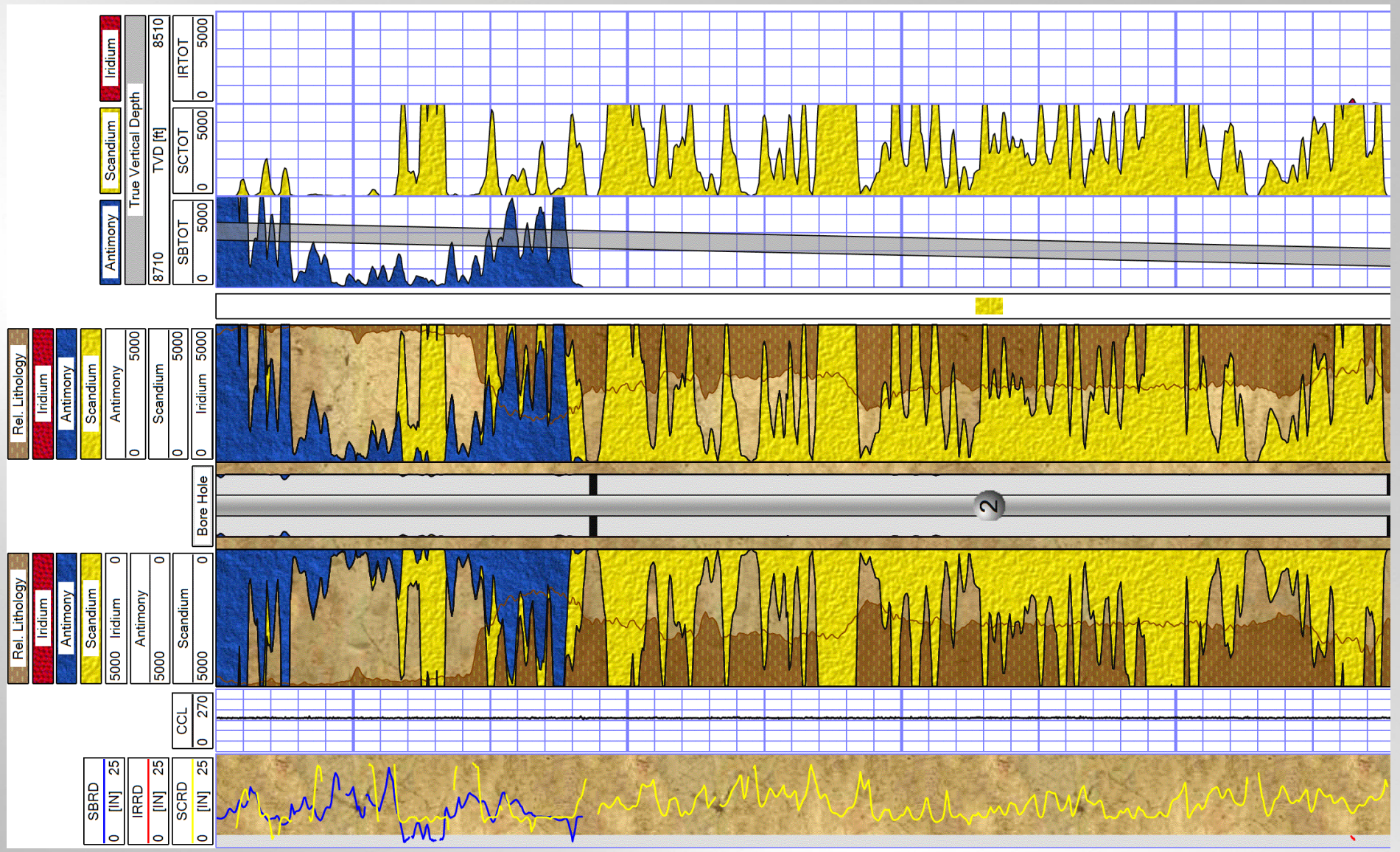
Example 3 – Untreated Stages



Example 4 – Isolation Failure at the Packer



Results Criteria

ProTechnics

- Greater than 50% of sleeve/plug failures
- Excessive proppant tracer carryover or contamination from sand production and losses during the cleanout

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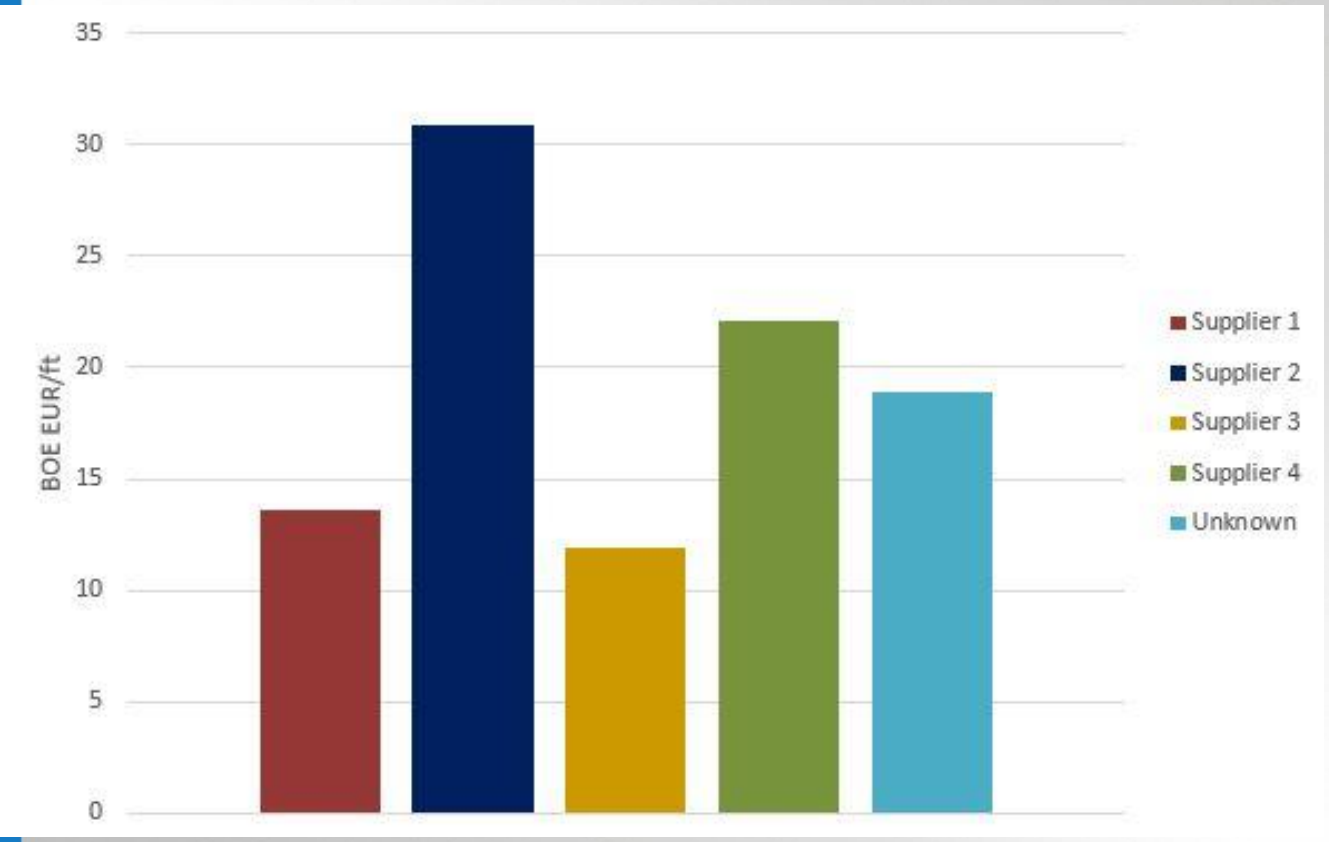
Study Results

ProTechnics

Isolation Type	Average Stages Isolated (%)	Number of Wells
Oil Swellable	18%	6
Water Swellable	46%	11
Dual Hydro-Mechanical	78%	2
Single Element Hydro-Mechanical	18%	10

Core Lab

Study Results



Production comparison between OHMS system providers

Anadarko Basin

- Failures from both ball seats & packers
- Ball seats: improper system designs in toe stages and possibly from erosion
- Rates typically > 90 bpm; seat failure if not designed properly
- SEPs provided isolation about 18% of the time

Study Results – Williston Basin

ProTechnics

Williston Basin Open Hole Isolation Results				
Well	Isolation Type	Total Stages Isolated (%)	Minimal Acting Differential Pressure (psi)	Rate (bpm)
B1	8' Swellable	7%	5,895	27.0
B2	8' Swellable	6%	5,440	33.0
B3	10' Swellable	50%	5,174	30.0
B4	Swellable	0%	5,240	31.0
B5	Blast Joint	0%	4,764	39.0
B6	Swellable	8%	5,855	18.0
B7	Dual Hydro-Mechanical	89%	6,205	24.0
B8	Dual Hydro-Mechanical	69%	5,802	38.0
B9	Dual Hydro-Mechanical	100%	5,423	30.0
B10	Swellable	0%	5,856	30.0
B11	Swellable	6%	5,597	30.0

Williston Basin Open Hole Isolation Results by Isolation Type				
Well	Isolation Type	Average Stages Isolated (%)	Minimal Acting Differential Pressure	Author Notes
Average	Swellable	5%	5647.2	Minimal isolation of stages
Average	Dual Element Hydro-Mechanical	86%	5809.8	Majority of stages show solid isolation
Average	Blast Joint	0%	4764.1	All tracers present in every stage

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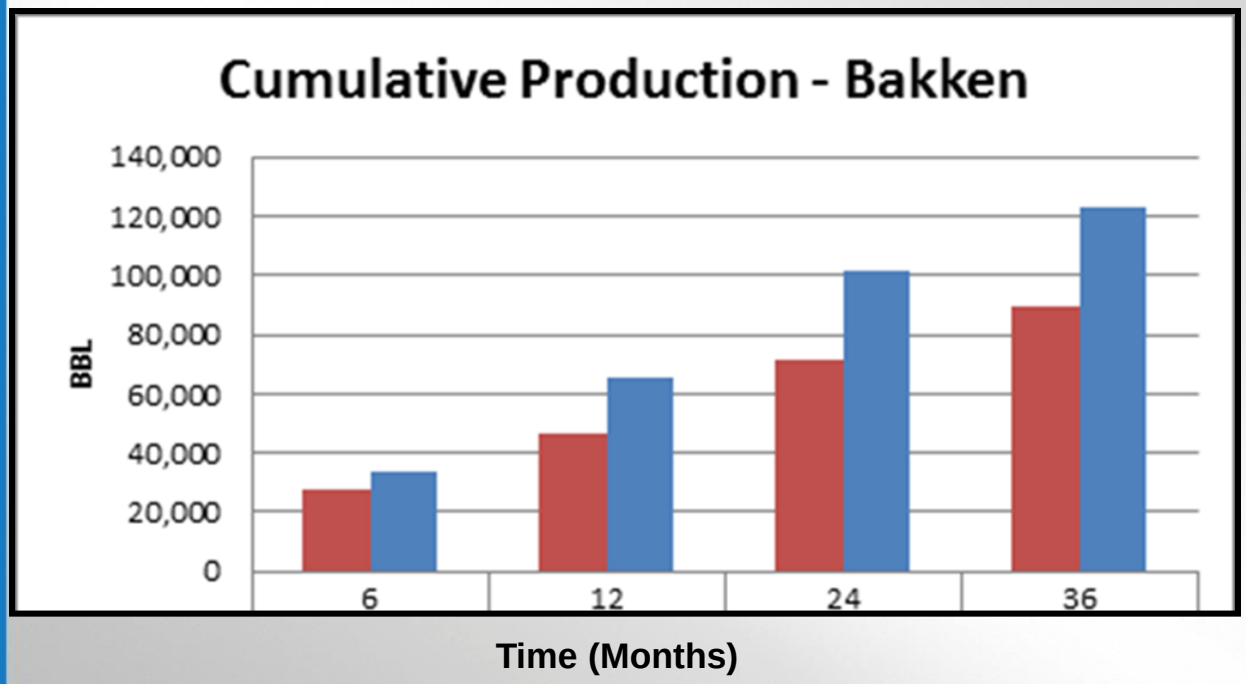
Study Results - Summary

ProTechnics

Williston Basin Production Analysis



SEP	27,464	46,832	71,334	89,376
DHM	33,962	65,244	101,132	123,286

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Conclusions

ProTechnics

- Cemented completion systems have difficulty achieving annular isolation in formations where there is a large concentration of natural fractures
- Both annular and internal stage isolation effectiveness can be impacted by isolation method and OHMS system provider
- Higher isolation rates between stages leads to higher production

Core Lab

Thank You!

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Questions And Discussion