The Impact of Perforating on Hydraulic Fracture Initiation in highly stress tough rock – a case study

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OUTLINE

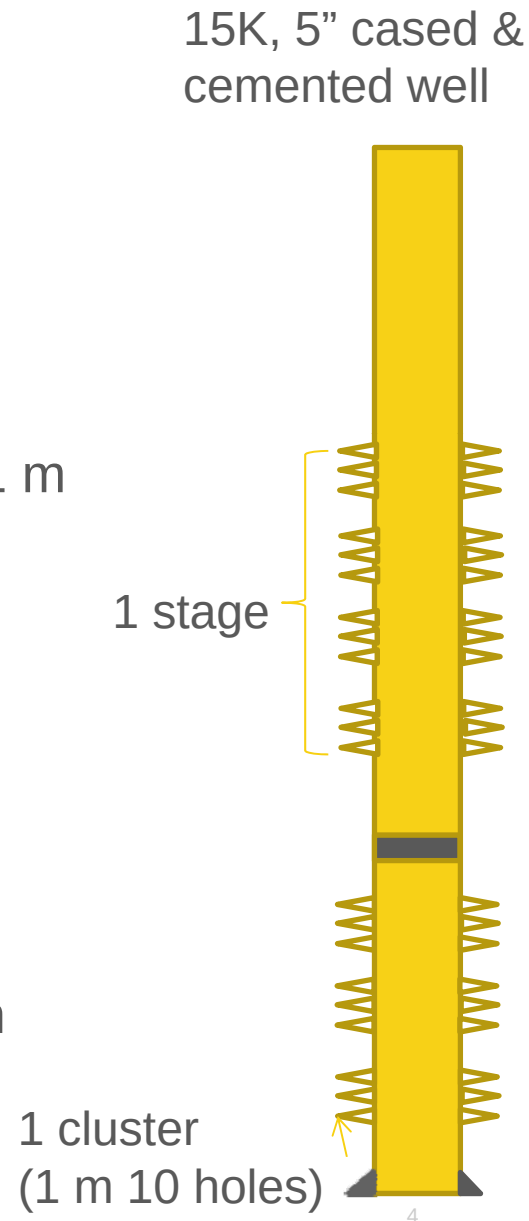
- Asset overview
- Completion Strategy
- Challenges, Causes
- Remedial Plan and Result
- Perforation methods comparison
- Conclusion

ASSET OVERVIEW

- Country: China
- Objective: To appraise BCG Play concept and assess productivity
- Appraising & Exploring using 9 vertical wells
  - Reservoir depth: 3500-4700 m
  - Multiple targets of sand stone and carbonate formation
  - **Very tight formation**: 0.002-0.05 mD
  - **High pore pressure**: 17-23 kpa/m (0.75-1.01 psi/ft)
  - **High stress**: Mixed reverse fault / Strike slip
  - **High rock strength** : YM 30-65 Gpa

Completion Strategy

- Fracturing using plug & perforation
  - 5 stages per well
  - Using heavy brine CaCl2
  - Max. pump pressure 14,200 psi
  - Initially, using limited entry perforation of 3 or 4 x 1 m interval w/ 10-12 shots/m
  - HCl and 100 mesh proppant
  - Hybrid slick water & gel frac
  - Intermediate proppant strength
- Pressure up 5-10 cycles for breakdown.
  - If fail to breakdown/ establish rate, add perforation



Perforation Strategy

- Limited entry perforation of 3 or 4 cluster of 1 m with spacing 5-10 m
  - To connect the clusters and create longer frac height
- Perforating gun, 2 7/8”, 18 g HMX, 60 deg phasing, 10-12 shot/m
  - 0.28” entrance diameter, 26” (660 mm)

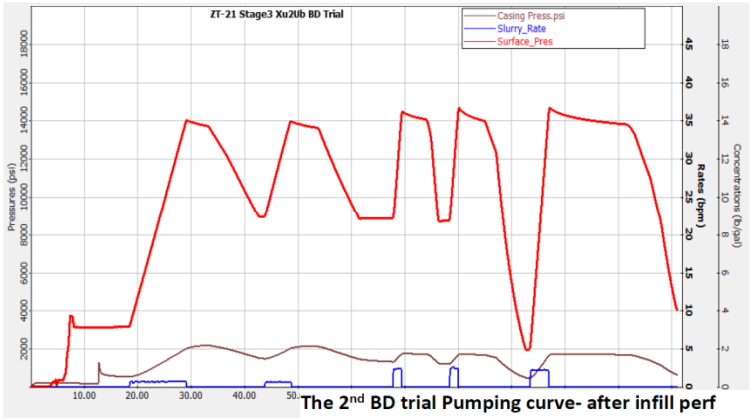
Test	EHD (mm)	Penetration (mm)
#1	7.3x7.1	691
#2	7.4x7.2	696
#3	7.6x7.3	671
Average	7.3	686

Challenges, Causes and Remediation

- Key challenges in first 3 wells (17 stages)
  - —Fail to break-down formation (4 stages)
  - —Not enough rate to continue w/ proppant fracturing (3 stages)
  - —Only 1 dominant cluster and limited height
- Potential Causes
  - —Tough, high rock stresses and high pressure
  - —Deep formation
  - —Near wellbore damage due to perforation/ drilling
- Several remediation measures
  - —Select less tougher rock (< 48 Gpa)
  - —Increase max. pump pressure
  - —Use heavier brine
  - —Spot acid to remove near wellbore damage
  - —Open hole completion
  - —Change perforating strategy (0 degree phasing, long perforation interval, sand jetting & Reactive charge)

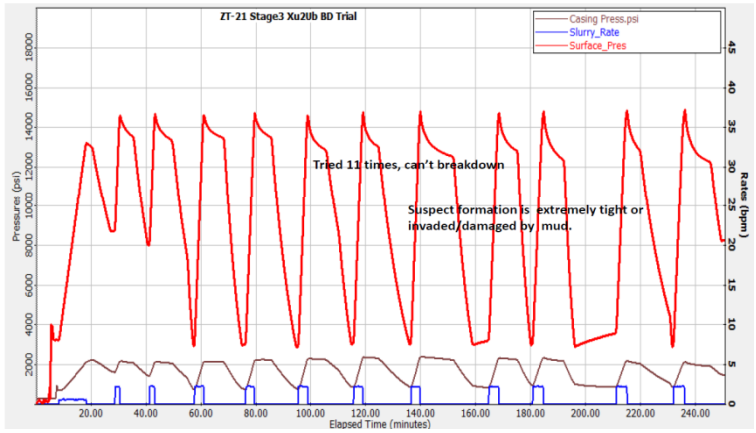
Example of pumping cycles in a stage at lower sandstone

The 1st BD trial Pumping curve- before infill perf



1. Reactive Charge, depth 4496-4499.6 m, 36 holes, 0.37 EHD, 60 degree phasing. Trialed 5 pumping cycle, no breakdown at pump limit 14,800 psi (1.58 psi/ft).

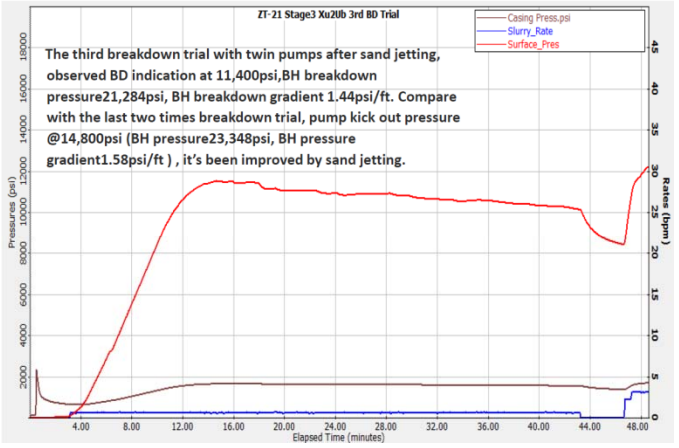
The 2nd BD trial Pumping curve- after infill perf



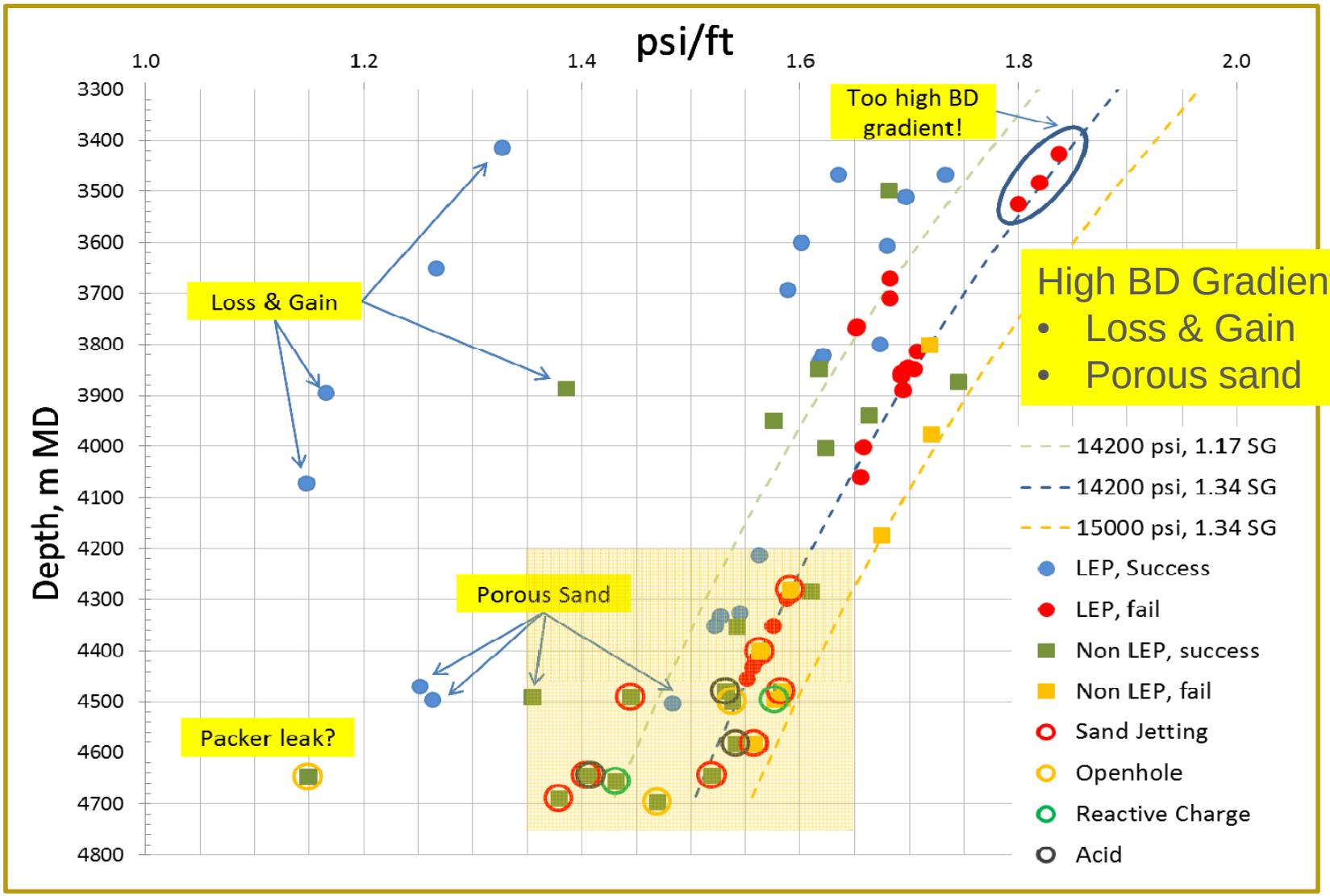
2. Casing gun, depth 4490-4495 m, 4496-4500, 11 holes/m, 0.28 EHD, 60 degree phasing. Trialed 11 pumping cycles, no breakdown at pump limit 14,800 psi (1.58 psi/ft)

3. Sand jetting, depth 4487-4496 m, 8 holes/m, 0.37 EHD, 60 degree phasing. BD gradient: 1.44 psi/ft

The 3rd BD trial Pumping curve- after sand jetting



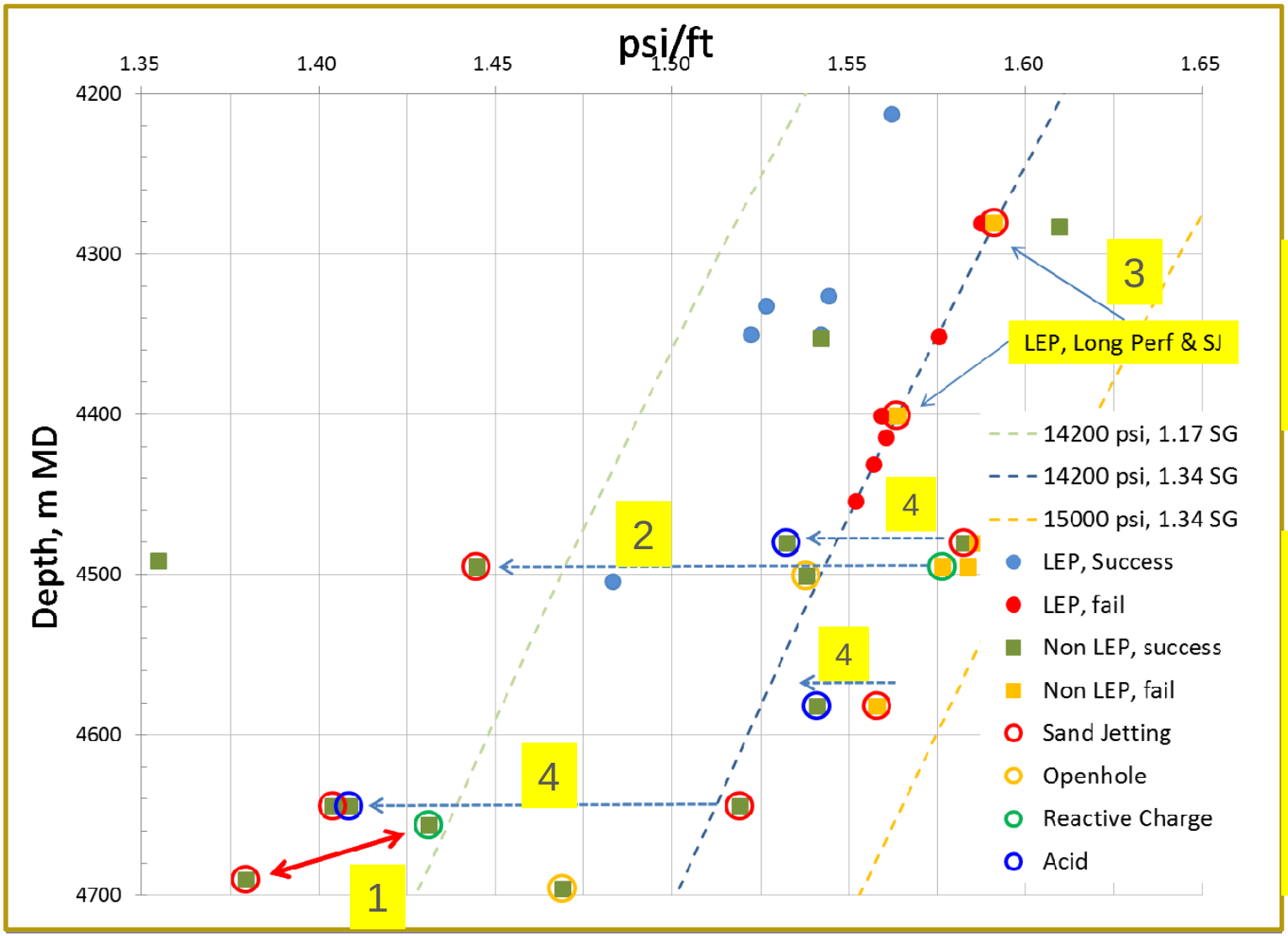
BREAKDOWN GRADIENT of ALL ATTEMPS



High BD Gradient besides
- Loss & Gain
- Porous sand

Some very high BD pressure when perforation using LEP

BREAKDOWN GRADIENT of ALL ATTEMPS



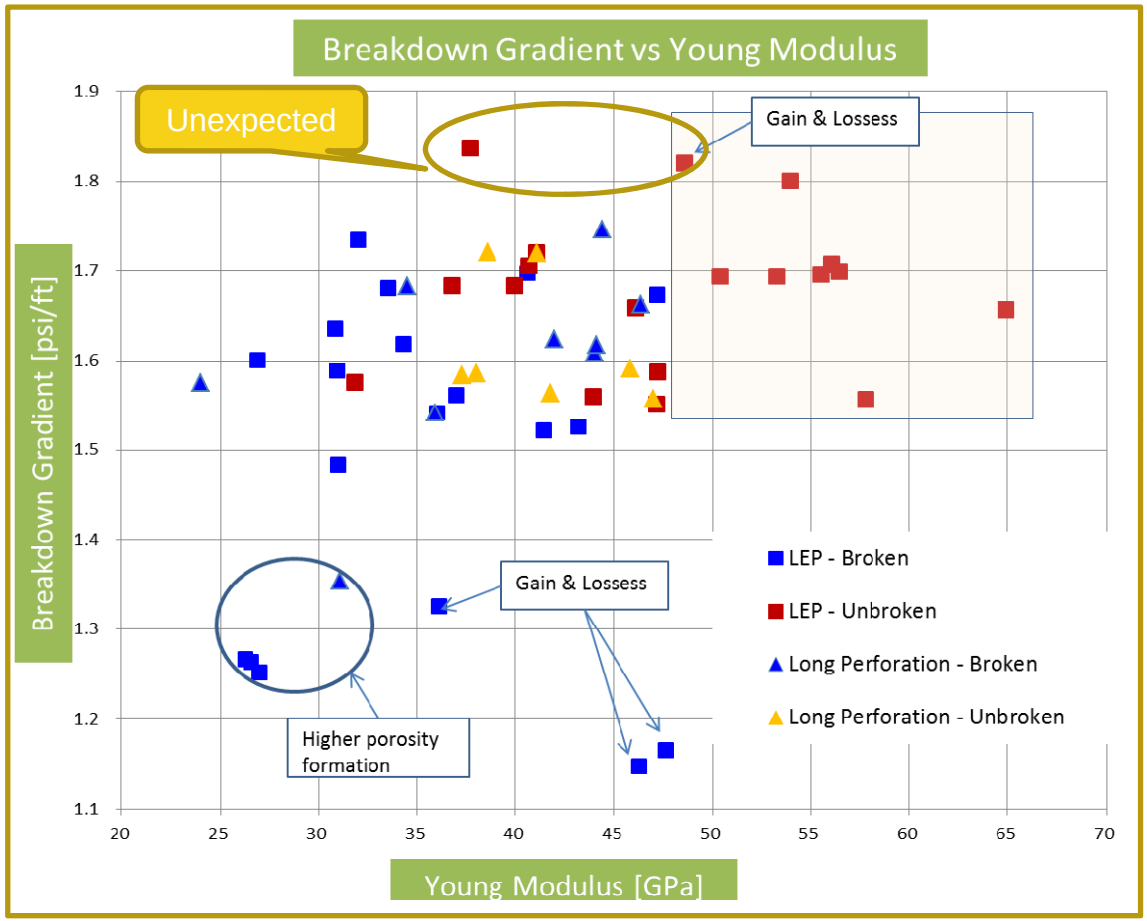
3. LEP, Long Perforation & Sand Jetting were fail.

4. Spot acid across perforation reduce the BD gradient & increase the rate to allow proppant frac

1. Sand Jetting has lower BD Gradient vs Reactive Charge at same sand

2. Sand Jetting BD the formation that was fail by Long perforation & Reactive Charge

LEP vs Long Interval perforation



- Success ratios of formation breakdown of Limited entry perforation and long interval perforation are similar (13/24 vs 8/15)
- Some unexpected fail to breakdown in LEP that may be caused

Conclusion

- Mother nature of the formation play the key role in breaking down the formation
  - —Breakdown is not an issue in Fractured tight and porous sand intervals
  - —Besides the above features, breakdown gradients are mostly high in the range of 1.37-175 psi/ft.
  - —Breakdown issues were predominantly encountered in the tight Xu2 SSt and the Xu4 Conglomerates
- Compare to LEP, Longer perforation ensures that the target interval is perforated to compensate the perforation, logging and drilling depth accuracy
- Limited entry 60 degree phasing shows slightly better breaking down formation compare to 0 degree phasing, possibly due to the lower tortuosity
- Reactive charge shows mixed success (1 success and 1 fail) and so far showed worse than Sand Jetting
- Encouraging result from Sand jetting by breaking down unbroken trials by other perforations but still encountered some failure to propagate the fracture/ establish rate. Need to combine with acid to remove near wellbore damage in certain type of formation or well condition.