Innovative and Optimized Delivery Methods

- Delivery methods date back to circa 1990
- The majority of changes in the industry are over technology, not delivery methods
- Some notable delivery advances include
  - Sparging
  - Permeable barriers
  - In-situ injections
  - Hydrofracing
  - Electro chemical
  - Injection wells
  - Direct-push
  - Pressure Injection
  - Pressure pulse
- In most cases, optimized delivery is designed to fight low-K
FIRE IN THE HOLE: Induced Secondary Permeability of a Low K Formation: What a Blast!

Robert Luhrs - Raytheon Company, Waltham, MA
Brian Sims – Apex Titan, Dallas, TX
John Yerton – Weaver Consulting Group, Golden, CO
Geologic Setting

- Dallas Area
- Thin layer of overburden
- Austin Chalk
  - Cretaceous
  - Recrystallized, fossiliferous, interbedded chalks and marls
  - Wind deposited from distal volcanoes (86 mya)
Austin Chalk

- Upper Kau (5-17’ bgs) is weathered (chemically oxidized and mechanically degraded) where exposed to meteoric water resulting in tan limestone
Austin Chalk
Potential Sources

- Former 1940’s manufacturing of aircraft and other commercial product
- Little detailed operations info available
- Area of interest never entirely redeveloped
Potential Source Investigation

- Negligible permeability within the massive chalk
- Groundwater ‘flow’ is controlled by the occurrence, distribution and connectedness of the bedding planes, marls and fractures
- Many monitoring wells took months to over half a year to return to static water level
Potential Source Investigation

- Site characterization considered small scale stratigraphy

- Concentration gradients can vary orders of magnitude over only several vertical inches
Feasibility Study Options

- Extremely low permeability, layered geology, mixed with multiple small areas of contaminant
- Site drivers included impending property resale and redevelopment
- Contaminant fingerprint of primarily TCE with little to no daughter products
- Initial approach used ISCO for “hot spot” remedy
- Transitioned to enhancing permeability and continuing ISCO based on real estate pressures
Initial ISCO Pilot Test

• Two ISCO pilot tests/interim actions were performed
  • One encircled a very small source/hot spot
  • The other a trench to treat a source located near a structure
• Both attempts resulted in very limited distribution despite sustained highly oxidative conditions
Hydrofracing

• A series of hydrofrac wells were installed to create interconnection between ISCO injection and groundwater monitoring locations

• Casings were installed, then lanced in place at target depths to correlate with the zone of concern
Hydrofracing

- Pressures were applied to the frac well until the rock fractured
- A high solid (>40%) mixture of water, guar powder, borax and an enzyme breaker, were mixed with 20/40 silica sand, and injected into each fracture zone
Hydrofracing

- Fracing was successful at the site, significantly improving ISCO treatment

Challenges

- Fracing primarily resulted in improving horizontal permeability
- Some areas resisted fracing
- Fracing had a variable distribution of success
Stubborn Area
Time to Innovate

• Time for redevelopment was getting shorter, and progress, while good, was slower than optimum

• Recalling a 25-30 year-old presentation
  • Xerox site located in Rochester, NY
  • Consultant – Haley and Aldrich
  • Trying to control off-site migration of chlorinated contaminants
  • 2-17’ of lacustrine sands, till and fill over bedrock
  • Primary contaminant zone was bedrock
  • Install vertical planar zones to divert water to recovery wells, reducing the number of wells needed

Something I always want to try
Why not use explosives?
Reasons? – Just Count Them

• When mentioned, others think you’ve lost your mind!
• Will it cause unintended consequences?
• Your environmental regulators likely won’t know how to respond
• Permitting obstacles
• Potential damage to nearby structures
• How to determine the scope?
• Will it work, and at what cost?
Concept for the Scope

• Determine the area needing fracturing.
• Cause the maximum amount of fracturing (particle size) without causing migration outside the area that can be contained.
• Ensure wave front energy from the blast will not cause damage to nearby infrastructure.
• Evaluate potential for subsurface remedial additives to cause unintended reactions.
• Design grid spacing, type and amount of charge, that will cause fracturing without damage to well field.
• Rock fluff and geotechnical considerations.
Stubborn Area
## Experience Vetting Vendors

- Requested RFPs from three blasting firms
- Site inspection and concept discussions with each

<table>
<thead>
<tr>
<th>Vendors</th>
<th>First Impression</th>
<th>Considerations</th>
<th>Cost</th>
</tr>
</thead>
</table>
| 1       | Cowboy, no big deal  | - I can attitude  
- Lets go!                                                                  | $    |
| 2       | Professional, thoughtful | - Strong interest in understanding the project intricacies and goals  
- Shared blasting theory, and how it could be tweaked to achieve goals  | $$   |
| 3       | Cautious, hesitant   | - Confused understanding of goals  
- Reluctance to vary normal approach  
- Distance                                                                  | $$$  |
Protecting Nearby Infrastructure

Limits for Blast-induced Ground Vibration

<table>
<thead>
<tr>
<th>Vibration Limit</th>
<th>Description</th>
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<tbody>
<tr>
<td>0.50 in/sec</td>
<td>Threshold limit for cosmetic cracking for old pre-stressed plaster in residential structures when low frequency ground vibrations (3 to 12 Hertz) are present.</td>
</tr>
<tr>
<td>0.75 in/sec</td>
<td>Threshold limit for cosmetic cracking in drywall construction for residential structures when low frequency ground vibrations (3 to 12 Hertz) are present.</td>
</tr>
<tr>
<td>1.00 in/sec</td>
<td>Vibration limit permitted by the United States Office of Surface Mining (OSM)</td>
</tr>
<tr>
<td>2.00 in/sec</td>
<td>Threshold limit for cosmetic cracking in residential structures when high frequency ground vibrations (&gt; 40 Hertz) are present.</td>
</tr>
<tr>
<td>5.2 in/sec</td>
<td>Cracking threshold for curing green concrete (7 to 13 hours old).</td>
</tr>
<tr>
<td>5.4 in/sec</td>
<td>50% probability of minor damage in residential structures (fine plaster cracks, opening of old cracks).</td>
</tr>
<tr>
<td>7.6 in/sec</td>
<td>50% probability of producing major damage in residential structures (fall of plaster, serious cracking).</td>
</tr>
<tr>
<td>10.0 in/sec</td>
<td>Cracking in concrete walls.</td>
</tr>
<tr>
<td>12.0 in/sec</td>
<td>Fall of rocks in unlined tunnels.</td>
</tr>
<tr>
<td>24.0 in/sec</td>
<td>Formation of new cracks in rock.</td>
</tr>
</tbody>
</table>

- **Threshold for concrete cracking is 2 IPS**
- **Concept was to stay to 1 IPS or less**
Blast Design Considerations

- Design was 75x150 area
- Distance to infrastructure, blast hole spacing and charge were calculated to result in 1 IPS or less
- Blast holes on 7’ spacings,
- 198 holes 30-40 feet deep
- Proper PPE during drilling included enclosed rigs
Blast Hole Design

- Blast hole design included multiple charges spaced vertically
- Booster charge and 15 lbs of ammonium nitrate packed per interval
- Perchlorate not considered to avoid ground water impacts
- Blast towards zone of weakness
# Blast Progression

|   | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
| 1 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 2 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 3 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 4 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 5 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 6 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 7 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 8 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 9 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 10|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 11|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 12|   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

**Key:**
- Dry
- Clear water
- Light Oxidant
- Heavy Oxidant
- Not Drilled
- Removed from Blast Grid
- Blasted
Water Level Observations

- Significant changes in water level as blasting progressed
- Well changes late in the blasting confirm interconnectivity
Permeability Comparison

- ISCO injections occurred throughout the project
- Injection rates demonstrate changes in permeability

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<tr>
<td>Initial well response</td>
<td>&lt;0.5 gpm</td>
</tr>
<tr>
<td>Post fracing</td>
<td>3-7 gpm @ 30 psi</td>
</tr>
<tr>
<td>Post blasting</td>
<td>Gravity drain 30 gpm</td>
</tr>
</tbody>
</table>

- Post blasting it took removal of 17,000 gallons to drop the water table 10 feet in the blast zone
Project Thoughts/Observations

- Blasting to increase secondary permeability is a viable option
- Care in project design, scoping, and vendor selection is important
- Blasting seems complex, but in this case was quite cost effective

Questions?