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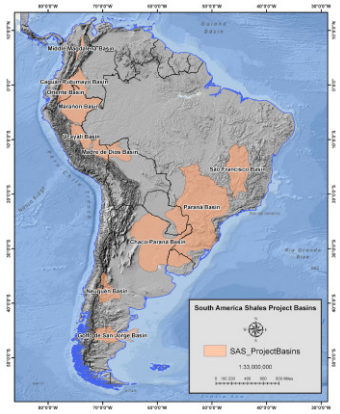


2013 Latin America Perforating Symposium

SLAP-23 Perforating Options Available Today in Horizontal Shale Oil and Gas Wells

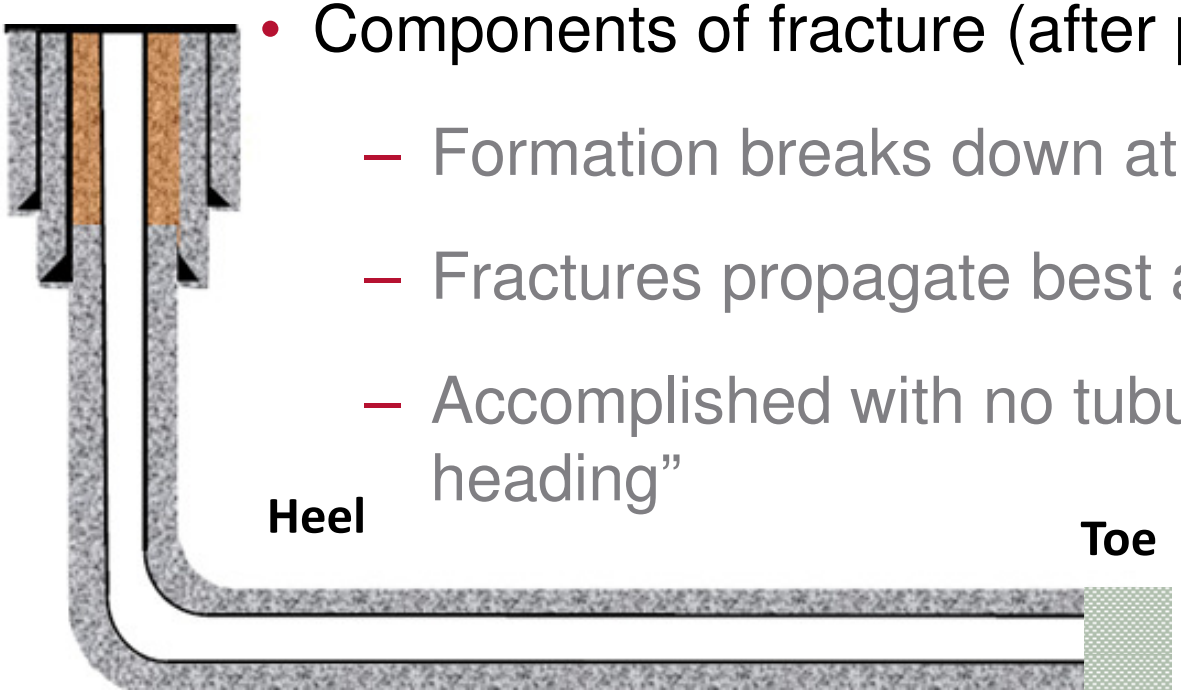
Kerry Daly, Weatherford

Typical Eagle Ford Well Costs

- Total well cost approximately $10 million
- Biggest single cost is formation stimulation, i.e. fracturing
- Regarding perforating choices, the biggest cost factors are:
  - Fracture standby costs
    - In US today, ≈$2,000 per hour
  - Coiled tubing (CT) run costs
    - In US today, ≈ $40,000 per run
  - Attempts to reduce these costs are driving development of
    - New perforating technology
    - New perforating techniques

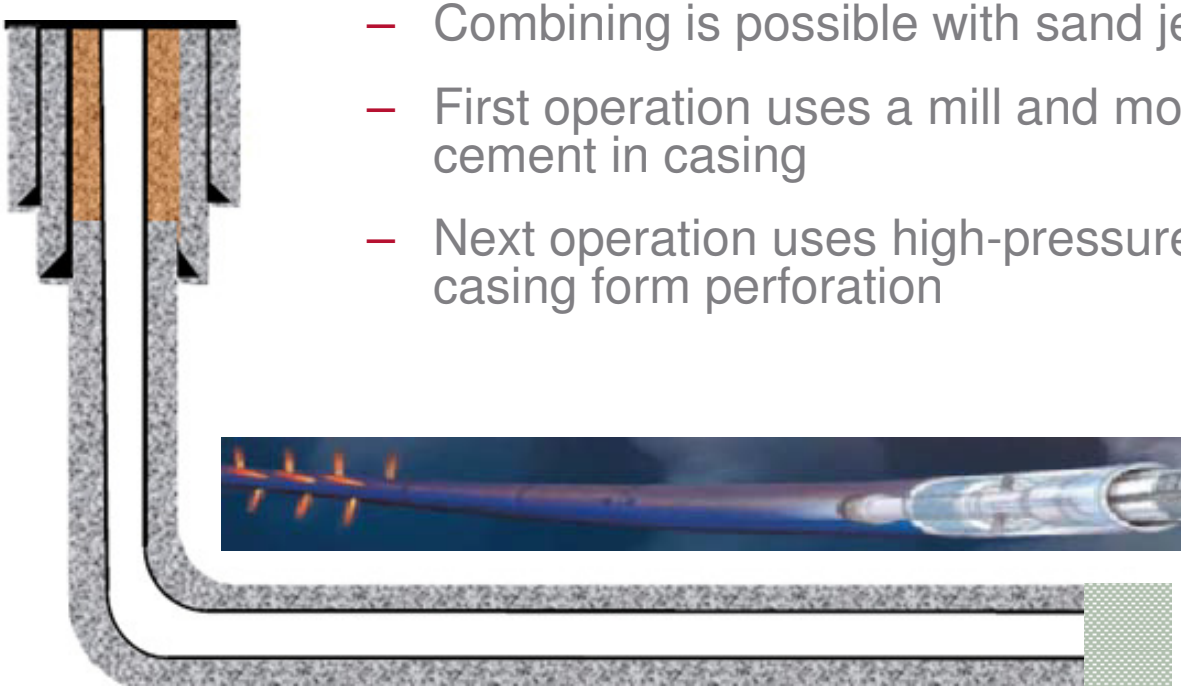
Typical Eagle Ford Wellbore

- Vertical section: 10,000 to 12,000 ft
- Horizontal lateral: 5,000 to 10,000 ft
- Typical casing: 4 1/2- or 5 1/2-in. OD
- Toe: considered the first 500 ft
- Components of fracture (after perforating)
  - Formation breaks down at ≈10,000 psi
  - Fractures propagate best at ≈100 bbl/min
  - Accomplished with no tubulars in wellbore, i.e. “bull heading”



Perforating Options

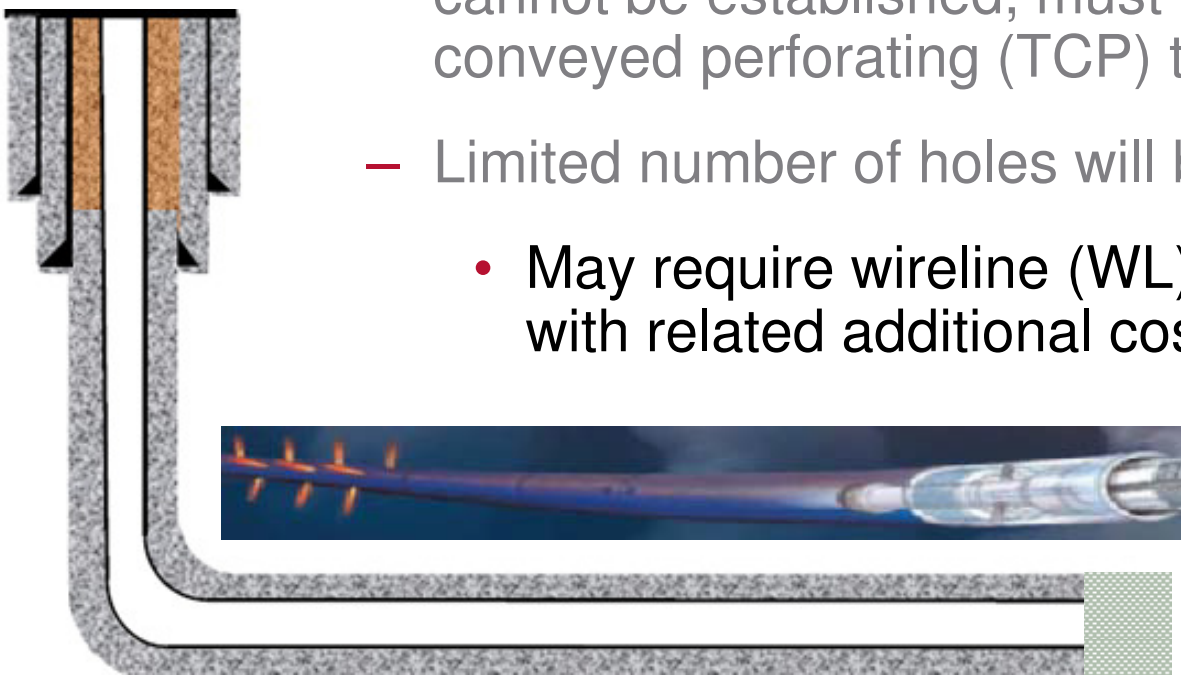
- The first operation after cementing is normally a CT clean-out run
  - Cost ≈$40,000/run (includes crane)
  - Establishes plugged back total depth (PBTD)
- Ideally, to save time and money, clean-out run should be combined with toe-prep perforating
  - Combining runs not possible with conventional explosive perforating guns
  - Combining is possible with sand jet perforation
  - First operation uses a mill and motor to drill-up any residual fill and cement in casing
  - Next operation uses high-pressure jets to direct sand against casing form perforation



Pumping unit may be required

Clean-out Run With Toe-prep Perforating

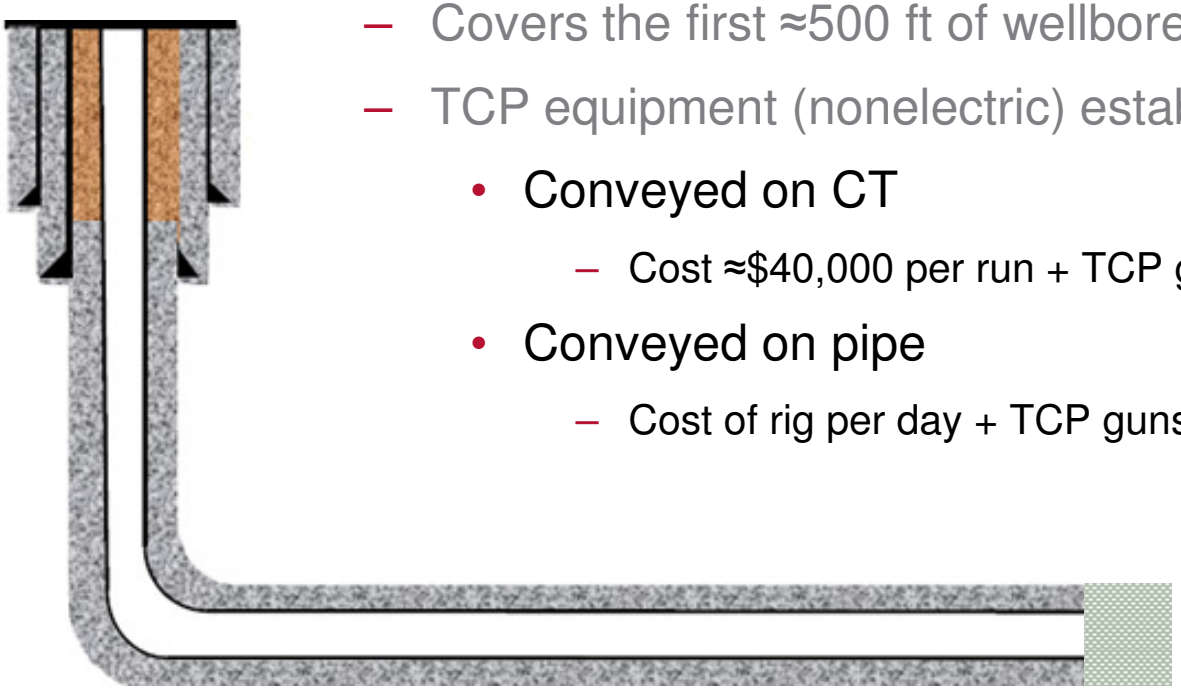
- Sand jet perforation
- Limited availability of equipment
- Cost unknown
- Risks:
  - If tool does not operate properly or if sufficient pump rate cannot be established, must perform traditional tubing conveyed perforating (TCP) toe prep
  - Limited number of holes will be created
    - May require wireline (WL) pump down perforating with related additional costs



Pumping unit may be required

Toe Preparation Using TCP

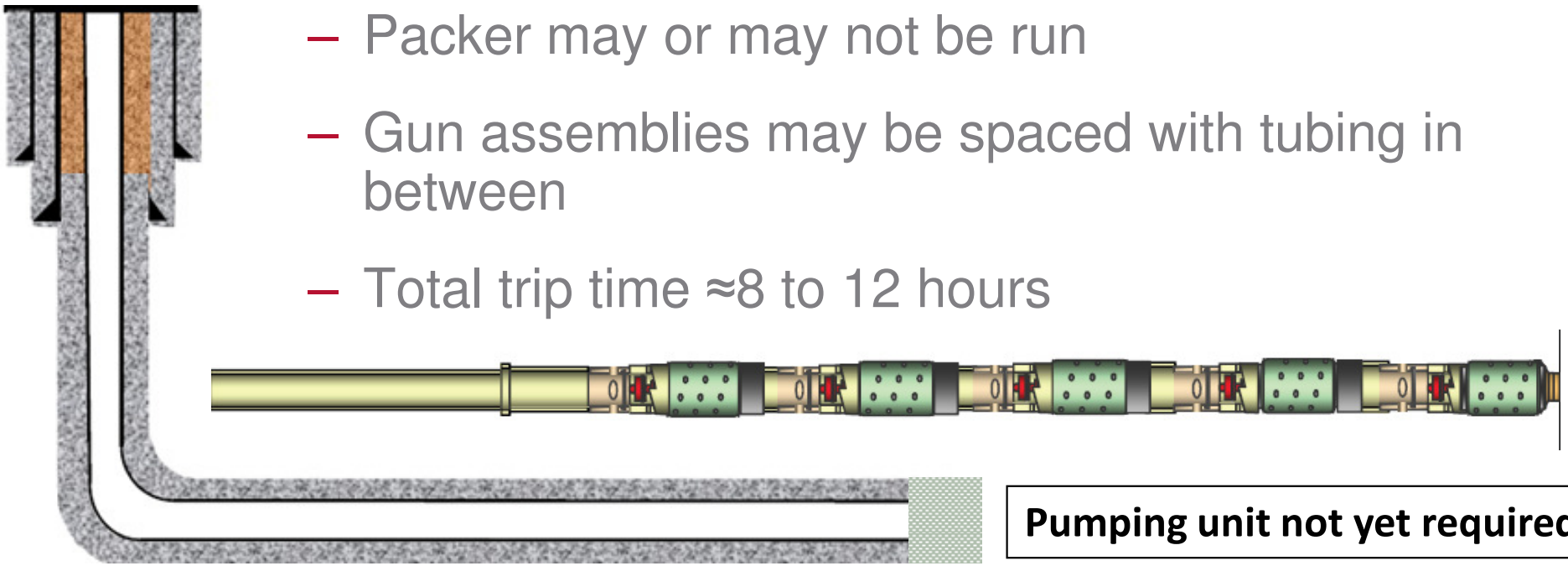
- First operation after cementing and cleanout run; no open perforations yet
- Maximum assembled length: ≈70 ft (limited by crane height/lubricator length)
- Consists of 1 to 10 guns
  - Length: 1 to 6 ft long, OD 2 3/4-, 3 1/8-, or 3 3/8-in.
  - Density/phasing: 4 or 6 SPF; 60 or 90° phase
  - Covers the first ≈500 ft of wellbore
  - TCP equipment (nonelectric) establishes the first perforations
    - Conveyed on CT
      - Cost ≈$40,000 per run + TCP guns
    - Conveyed on pipe
      - Cost of rig per day + TCP guns



Pumping unit not yet required

Pipe Conveyed Toe Preparation Using TCP

- Multiple pressure-activated firing heads fired at the same time
- May or may not have time delays attached
- Job parameters:
  - WL correlation not required, can use pipe tally
  - Packer may or may not be run
  - Gun assemblies may be spaced with tubing in between
  - Total trip time ≈8 to 12 hours



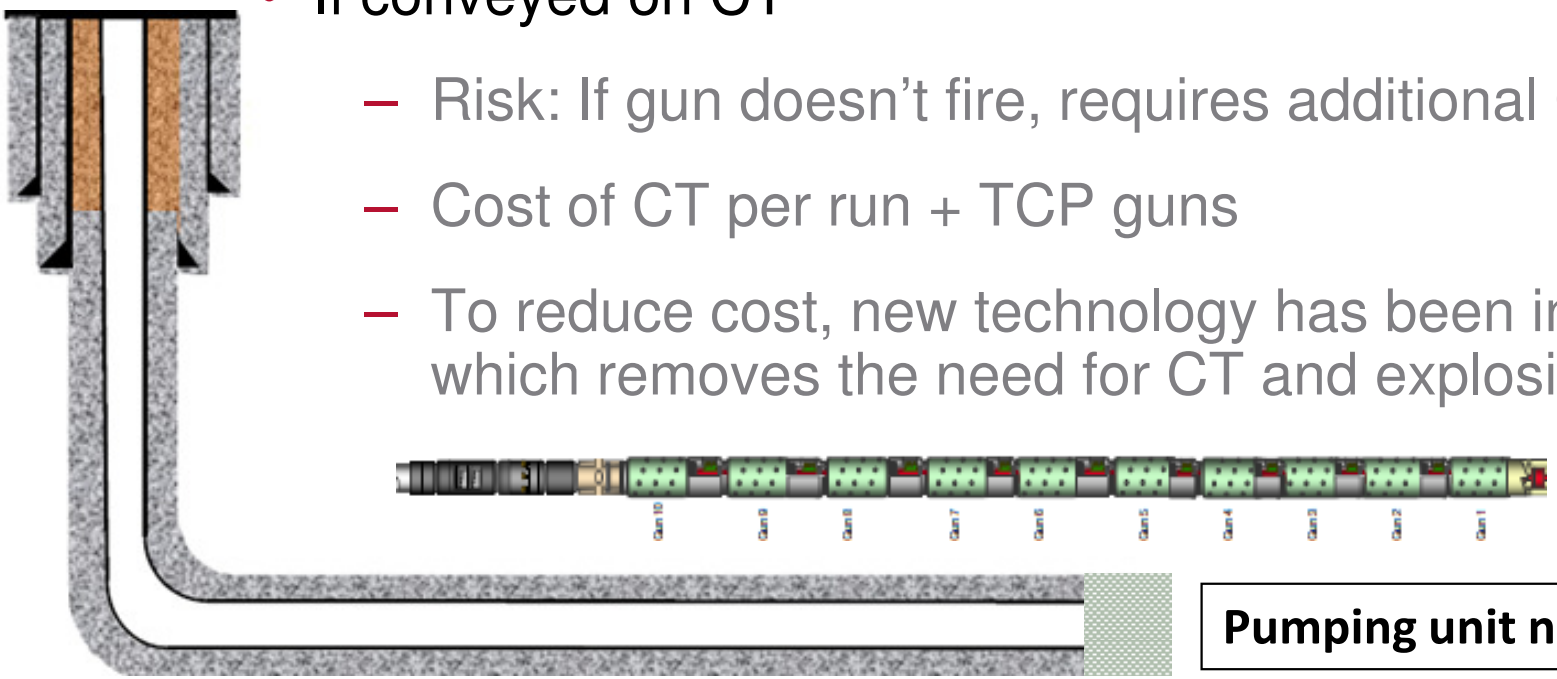
Pumping unit not yet required

CT Conveyed Toe Preparation Using TCP

- One pressure-activated firing head or ball-drop-differential firing head fires first
- Time delays between guns allow CT to move to next zone
- Number of guns and zones limited by surface lubricator and crane height
- Job parameters
  - WL correlation not required, can use CT depth recorded on clean out run
  - Total trip time ≈6 to 10 hours
  - Compared to conveying on pipe, this takes longer but is normally cheaper

Toe Preparation Using TCP Method Comparisons

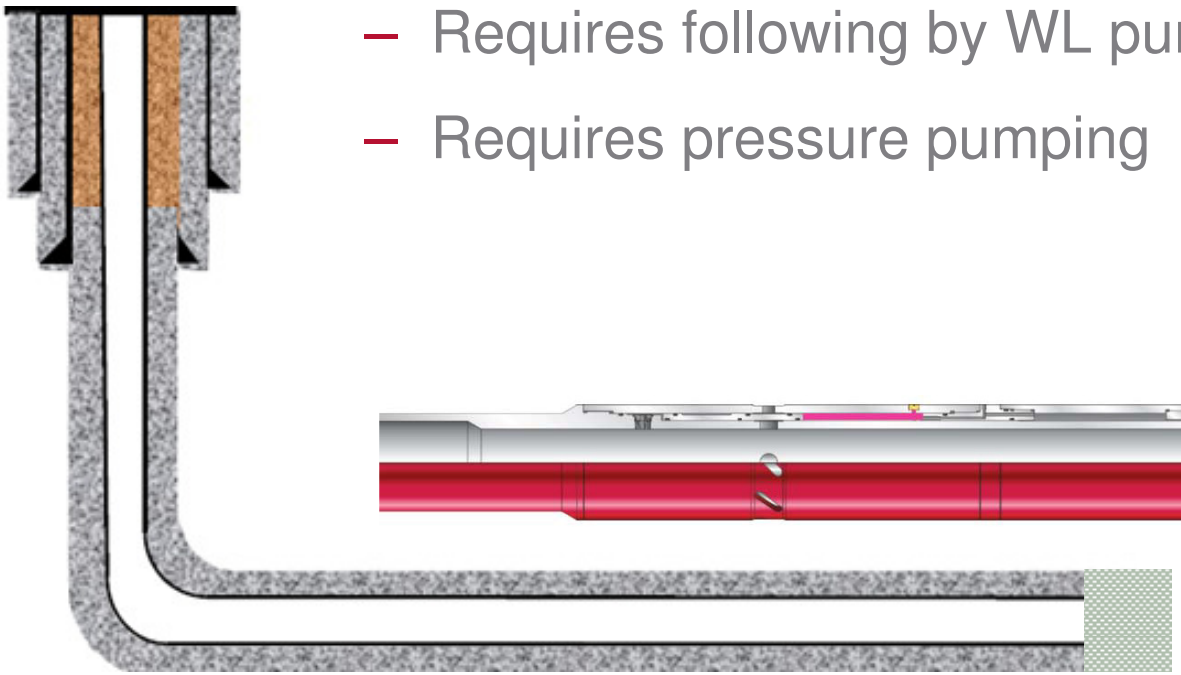
- If conveyed on pipe
  - Risk: If gun doesn't fire, additional trip on pipe is required
  - Cost of workover rig + TCP guns
  - To reduce cost, new technology has been invented which requires no rig
- If conveyed on CT
  - Risk: If gun doesn't fire, requires additional CT run
  - Cost of CT per run + TCP guns
  - To reduce cost, new technology has been invented which removes the need for CT and explosives



Pumping unit not yet required

Toe Preparation New Toe Sleeve Technology

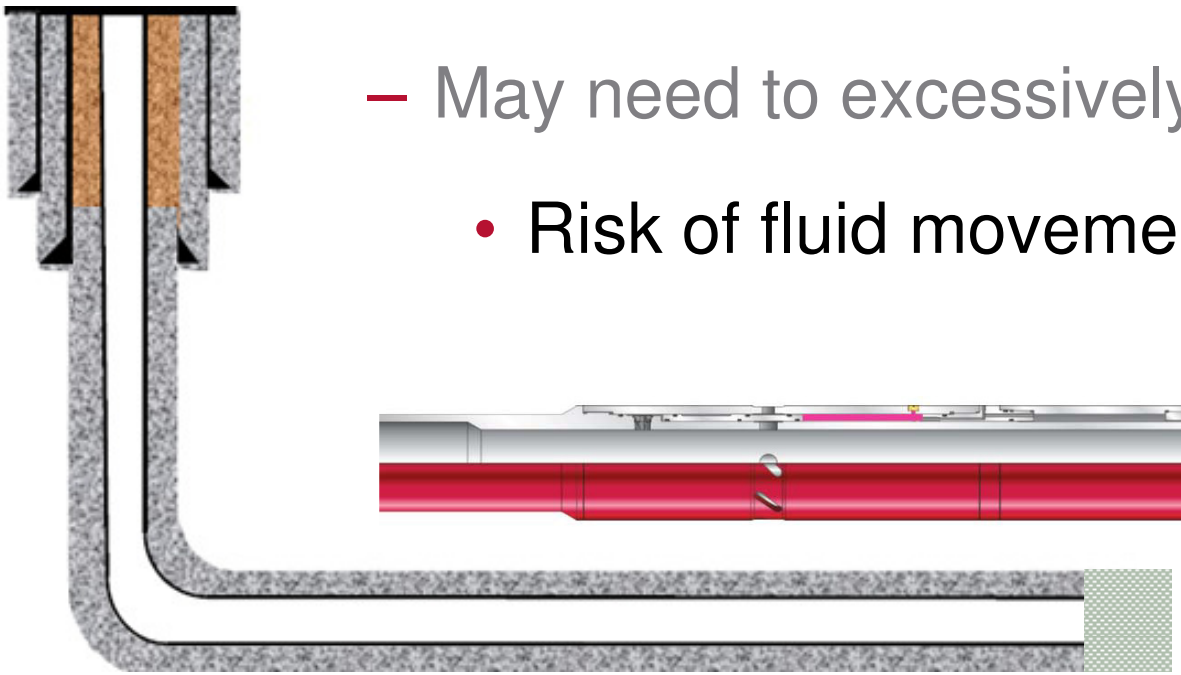
- Attached to casing just above shoe and cemented in place
- After placing cement, circulate a ball and plug to shift sleeve
  - Opens ports in contact with formation to allow fracturing
- Removes CT or workover rig costs and run time involved
- Limited number of holes
  - Requires following by WL pump down perforation
  - Requires pressure pumping



Pumping unit may be required

Toe Preparation New Toe Sleeve Technology Risk

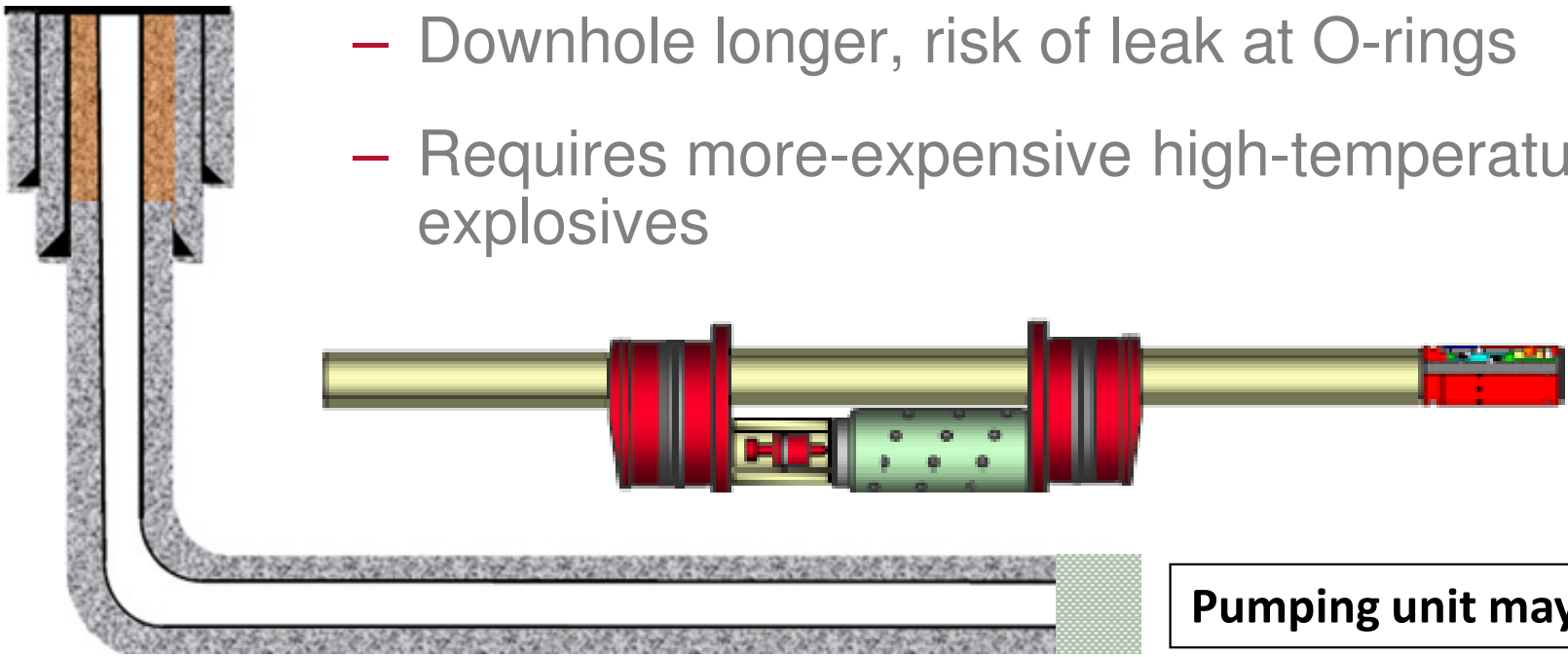
- If sleeve does not operate properly or if unable to establish sufficient pump rate, operator must perform traditional TCP toe preparation
- To limit cement sheath at tool
  - May need to over displace cement
  - May need to excessively retard cement
    - Risk of fluid movement behind casing



Pumping unit may be required

Toe Preparation New Toe Gun Technology

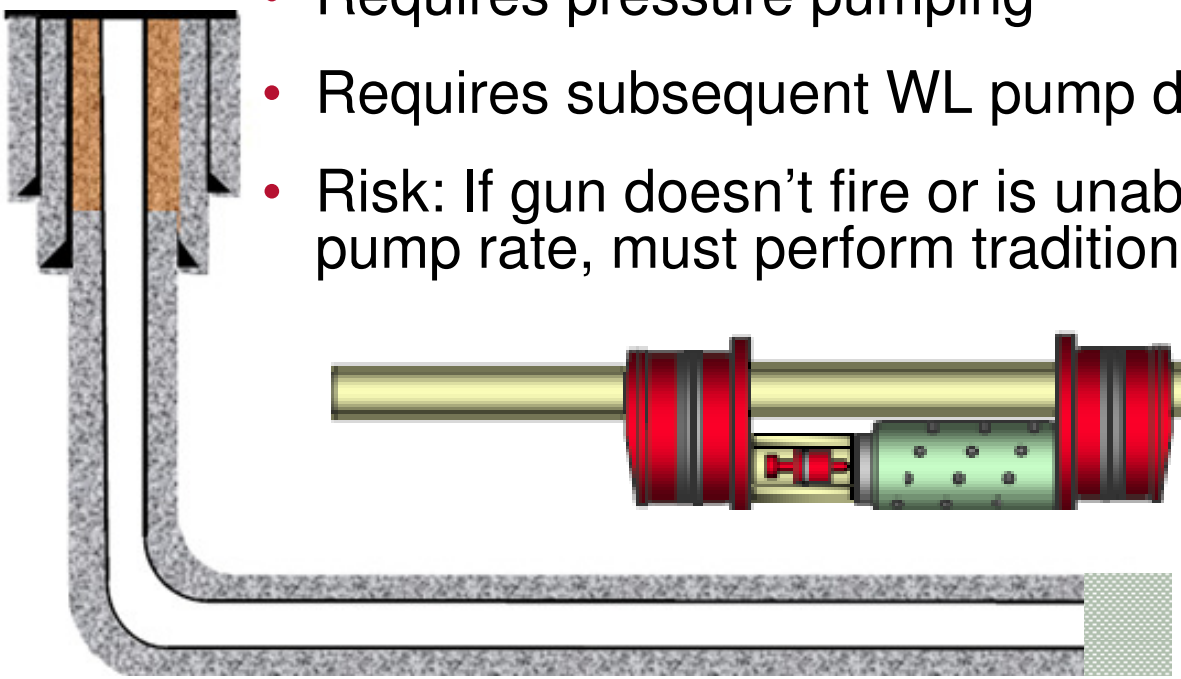
- Attached to outside of casing
  - Run just above shoe and cemented in place
  - Requires larger borehole, which carries additional drilling cost
- Guns must be run at same time as casing
  - Downhole longer, risk of leak at O-rings
  - Requires more-expensive high-temperature explosives



Pumping unit may be required

Toe Preparation New Toe Gun Technology

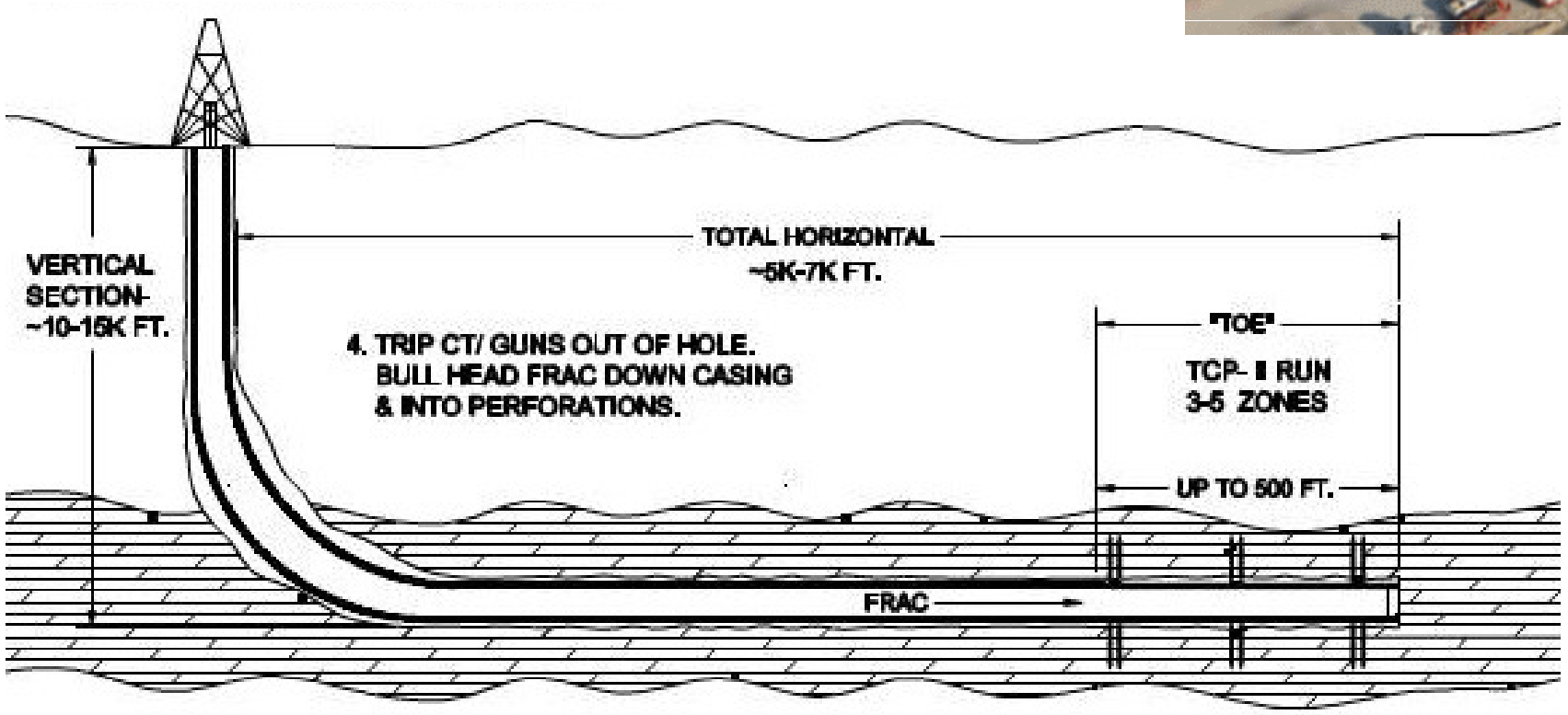
- Gun fires in two directions
  - Away from casing into the formation to create flow path
  - Into casing to complete flow path
- Removes CT or workover rig costs
- Limited number of holes
- Requires pressure pumping
- Requires subsequent WL pump down perforation
- Risk: If gun doesn't fire or is unable to establish sufficient pump rate, must perform traditional TCP toe prep



Pumping unit may be required

After Toe Preparation, Fracture First Stage

- Perforations have established flow path
- Components of fracture (after perforation)
  - Formation breaks down at ≈10,000 psi
  - Fractures propagate best at ≈100 bbl/min
  - Bull-head through casing
    - Allows higher pump-in rates



After Fracturing First Stage, Perforate Next Stage

- WL pump down plug and perforation
  - Cost ≈$10,000 per stage
  - In single run
    - Sets composite fracture plug, isolating previous stage
    - Fires ≈1 to 10 guns over staged interval (determined by operator)
  - Same gun lengths and configuration as TCP
  - Electric detonators, normally select-fire (+ and – switches)
  - May have pressure on wellbore, ≈1,000 to 4,000 psi at surface
    - Pressure-control equipment required
  - Requires high volumes of fluid to position guns ≈10 to 18 bbl/min typical
  - Maximum run speed - 200 ft per min

After Fracturing First Stage, Perforate Next Stage

- WL pump down plug and perforation
  - Normal run time is ≈2 to 3 hours
  - At end of run, circulate a ball into the fracture plug, which allows fracturing this stage
  - Risks:
    - High failure rate – statistically 1 in 7 (15%) experience some type of failure
    - Simplest failure is electrical short resulting in 4 to 6 hours lost time at $2,000 per hr = $8,000 additional fracture equipment stand by cost.
    - Most complex failure is parted line with live guns lost in hole resulting in several days (≈50 hours) at $2,000 per hr additional cost
  - Rewards:
    - Limiting time and saving costs when considering fracture standby
    - Benefits outweigh the risk!
    - WL pump down plug and perforation not going away

After Fracturing First Stage, Perforate Next Stage

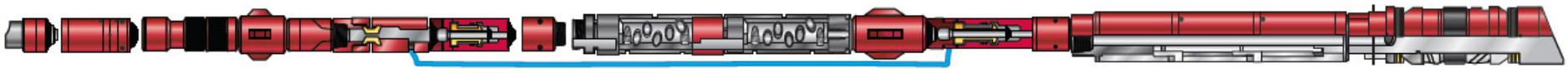
- WL pump down plug and perforation
  - Other risks:
    - Formation fails to break down
    - If cannot generate ≈10 to 18 bbl/min, then cannot pump down WL
    - If WL bridges out during pump down due to fill from previous fracture, remember that the wellbore has not been re-entered since
    - In these cases, WL and other options are needed

Optional TCP and CT Plug and Perforation Systems

- Set composite fracture plug and fire guns
  - With annular pressure
    - Formation must hold pressure in order to fire, which is not always possible as it has just been broken down
    - Requires CT conveyance, cost ≈$40,000 (includes crane)
    - Plug and perforation system cost ≈$15 to 20,000
    - Benefits
      - Not pumping down, so not subject to high-pressure fluid ingress
      - Not electrical, so not subject to electrical safety issues or shorts
      - One-trip system saves the cost of a CT run
    - Risks
      - Slow: ≈6 to 8 hour trip on CT incurs fracture standby costs
      - Pressuring against firing-head pins, potential for premature firing

Optional TCP and CT Plug and Perforation Systems

- Set composite fracture plug and fire guns with tubing pressure using a new proprietary system, current record
  - More than 100 successful runs in Canada
  - Re-engineered system for use in US
  - First US run successfully completed in April 2013
    - Requires CT conveyance
      - Cost ≈$40,000 (includes crane)
    - Plug and perforation system cost ≈$25,000 to $30,000



Optional TCP and CT Plug and Perforation Systems

- Set composite fracture plug and fire guns with tubing pressure
  - Benefits:
    - Not pressuring against formation
    - Not pressuring on firing head until after plug is set
    - Not pumping down, so water usage is less and no high-pressure fluid ingress
    - Not electrical, so not subject to electrical safety issues or shorts
    - One-trip system saves the cost of a CT run
  - Risks:
    - Slow: ≈6 to 8 hour trip on CT, incurring fracture standby costs

After all Stages Perforated and Fractured

- CT mill-up of composite plugs
- Flow-back and well-test clean-up
  - Lasts from two days to several months, depending on client's production plans
- Well is put into production

Summary of Steps

1. First run after cementing is CT clean-out
   - May include sand-jet perforating
     - Eliminates TCP toe preparation but requires wireline pump down plug and perforation
2. Toe preparation
   - Most common is TCP run on CT
   - Optional systems, both may require WL pump down plug and perforation:
     - Toe sleeve
     - Toe gun
3. Fracture (non perforating)
4. WL pump down plug and perforation
   - If cannot get down due to fill in casing or formation did not break down
     - CT and TCP plug and perforation, annulus pressure
     - CT and TCP plug and perforation, tubing pressure
5. Fracture (non perforating)
6. After all stages perforated and fractured, CT mill-out of composite plugs

- NOTE – In all operations, time spent is one of the most critical factors in controlling costs due to the cost of fracturing equipment stand by.

Application in Latin America

- Activity is building in many basins
- Technology is easily transferrable
  - Dependent on availability of equipment
  - Dependent on availability of qualified service personnel
- Questions?