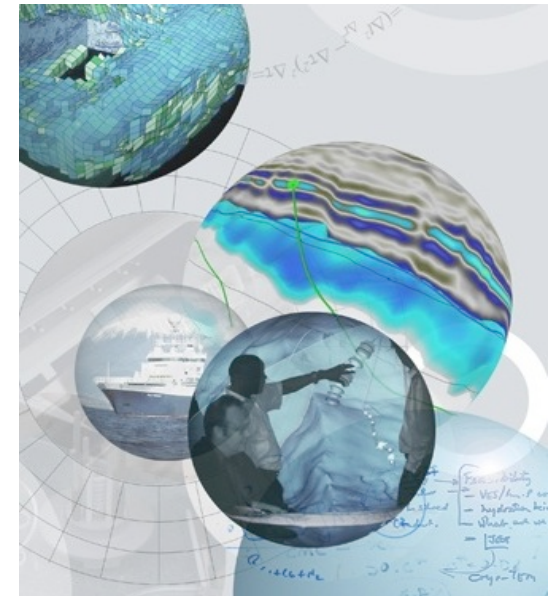


Some Drilling Thoughts



February 2018
Iain Cooper



Two Pieces of Relevant Background Information

- Coiled Tubing Drilling – Current State of the Art
- Laser Drilling – With & Without Drilling Fluids



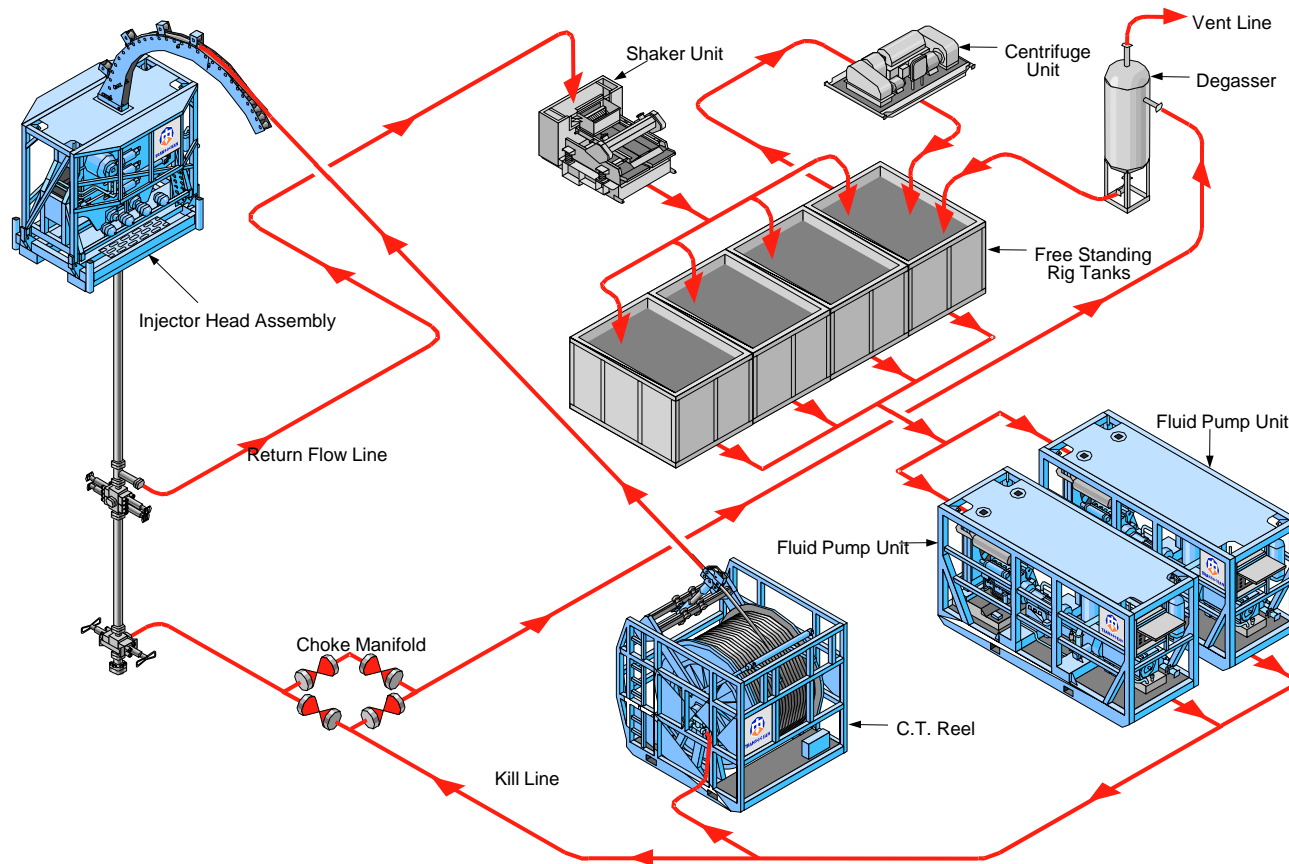
Coiled Tubing Drilling

- The use of coiled tubing (continuous pipe), stored on a reel at surface, combined with downhole mud motors to turn the bit to deepen a wellbore.
- MWD / LWD mud pulse and wired telemetry are available to directionally steer the wellbore to the zone of interest.



- Continuous pumping vs stopping at each connection
- Weight : CT can be pushed into the horizontal section (and in shallow wells) with the aid of the Injector Head
- Superior directional control due to steering at BHA (reduced reactive torque effects)
- Capable of higher Dogleg (up to 45deg/100ft)

Typical Surface System – CTD Land Job.

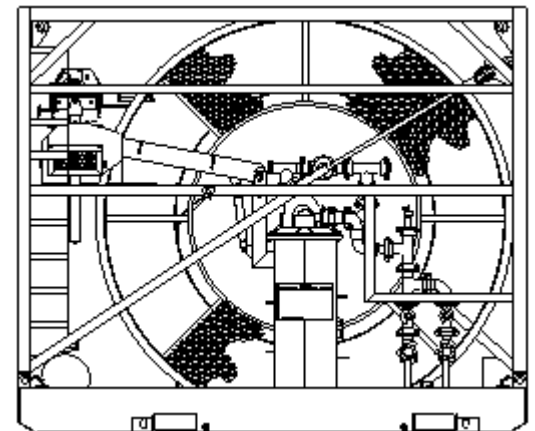
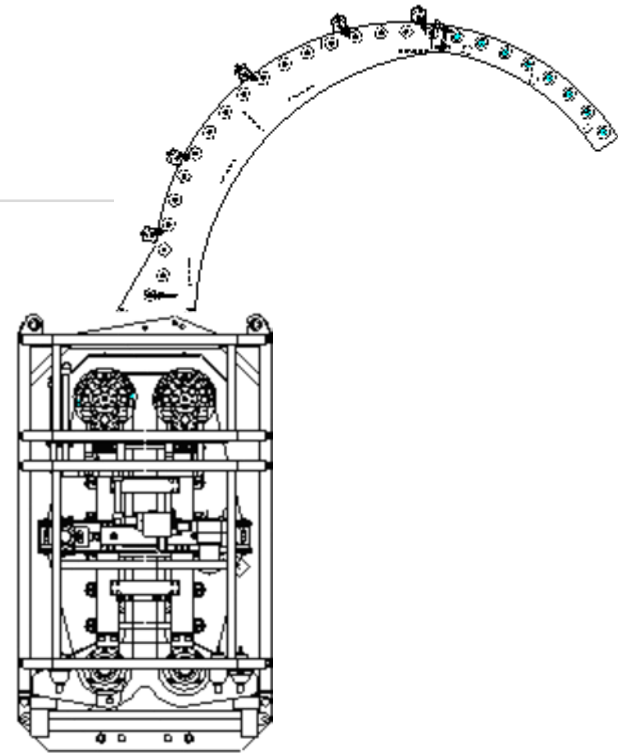


Flow Line Layout Example: Stand Alone Operation Rig Tank System

Typical Surface System – CTD Land Job.

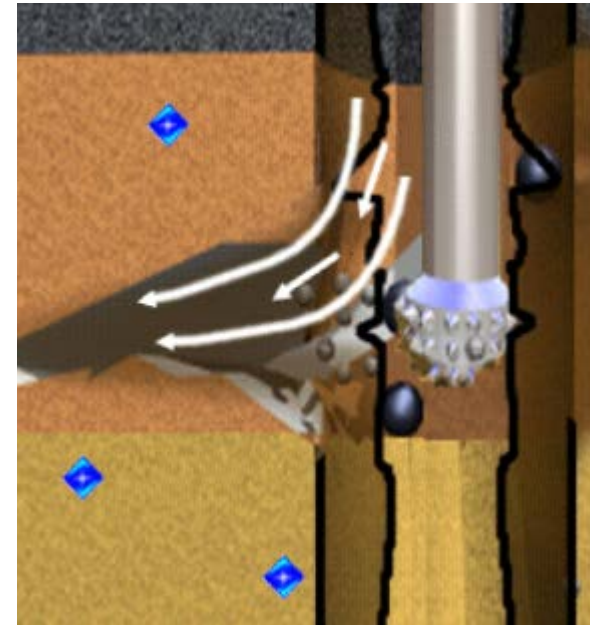
Coiled Tubing Drilling Unit

- CT Drilling equipment usually includes:
 - coiled tubing and coiled tubing reel
 - 10,000' of 3 1/2" OD CT
 - 18,500' of 2.375" OD CT
 - injector head
 - Electric powered, with up to 200K lbf pull
 - power pack
 - pressure control equipment (PCE)
 - 10,000 psi is the most commonly used
 - 5,000 – 15,000 psi can be secured
 - control cabin



Underbalanced vs Overbalanced Drilling

- **Overbalanced drilling** : drilling fluid pressure > bottomhole pressure (pore pressure). Reservoir fluids are not allowed to enter the wellbore.
- **Underbalanced drilling** : BHP < pore pressure of the rock: Reservoir fluids are allowed to enter the wellbore -> separated at surface
- The underbalanced technique is used to:
 - prevent formation damage
 - minimize many drilling-related challenges, such as loss of circulation and differential sticking,
 - increase rates of penetration,
 - minimize completion costs,
 - increase hole-cleaning efficiency,



Latest CT System



Specifications

BOP's	10,000 psi
Deployment Length	100'
Working Load	250,000 lbs.
CT Injector	200,000lbs Pull
CT Injector	60,000lbs Snub
Pipe Size	2"-3.5"
Spool Weight	65MT Max
Fluid Storage	280 bbl. Water and Mud
Fluid Pump	2X425HHP
Fluid Pump	10,000 psi
Generator	3X500Kw (600V)
Operating Temp All Equipment	-20 to 50 Deg C
Accumulator	6 Station self-contained skid X 2 PCE capacity
Fluid Pump	2X425HHP
Generator	3X500Kw
BOP Handling	10T Capacity



Latest CT Drilling System Specifications

CTDirect System Specifications

Nominal OD	3.12 in [79.25 mm]
Hole size	3.625–4.75 in [92.08–120.65 mm]
Max. allowable operational overpull	30,000 lbf [40,675 N.m]
Max. WOB	11,500 lbf [51,155 N]
Max. dogleg severity	35°/100 ft [35°/30 m]
Max. orienter torque	
Forward	500 ft.lbf [678 N.m]
Reverse	1,900 ft.lbf [2,576 N.m]
Nominal length, including motor [†]	60 ft [18.3 m]
Max. internal pressure	15,000 psi [103.4 MPa]
Max. annular pressure	10,000 psi [68.9 MPa]
Operating temperature range	14 to 302 degF [–10 to 150 degC]
Max. flow rate	130 galUS/min [492 L/min]
Produced fluids	Gas, water
Hydrogen sulfide	Up to 20%
Operational	
Cable requirement	Heptacable inside coil
Coiled tubing size	2.375 in [60.33 mm]
Pressure barriers	Multiple

Measurement

Inclination	Industry standard
Azimuth	Industry standard
Toolface	Gravity and magnetic
Natural gamma ray range	0 to 250 gAPI
Shock and vibration sensor peak range	500 <i>g</i>
Annular and internal pressure sensor range	0 to 10,000 psi [0 to 68.9 MPa]

Fluid Compatibility

Nitrogen	Up to 99% nitrogen, 1% water
Lubricant	Radiagreen®, up to 3%
Methanol or ethylene glycol	40% methanol or 100% ethylene glycol
Caustics	Sodium hydroxide
Corrosion inhibitor	ASTM International SA193 (amine based)
Potassium chloride	Up to 2%

[†] Dependent upon motor

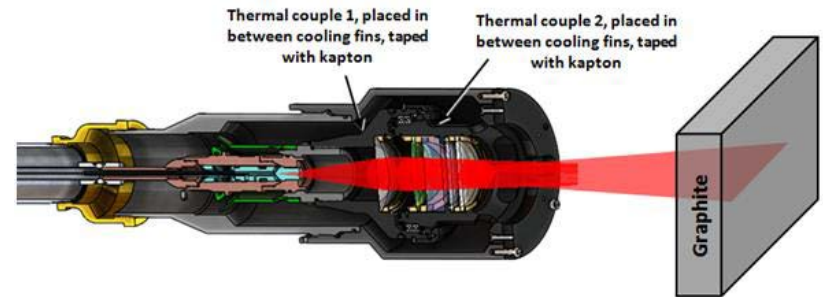
Laser Drilling

FORO
ENERGY

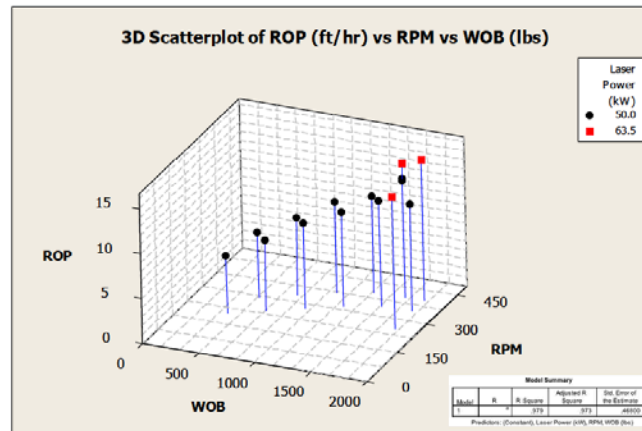


Foro Energy: Laser Drilling Update

- Currently Using 60kW laser (100kW laser recently demoed)
- Laser-induced thermal spallation
- Roller cone vs Foro Bit (45 ksi Basalt). For same ROP roller cone needed 13 klbs, laser <1klbs



- Drilling process optimization is underway at 60 kW:
 - Sample Rock: 35 ksi Dolomite, 8.5••
 - Parameters: Laser Power, Weight on Bit (WOB), Rotations Per Minute (RPM), and Torque (ft-lbs)
 - Initial results to be optimized: >15 ft/hr, <2000lbs, <250 ft-lbs, >20kW



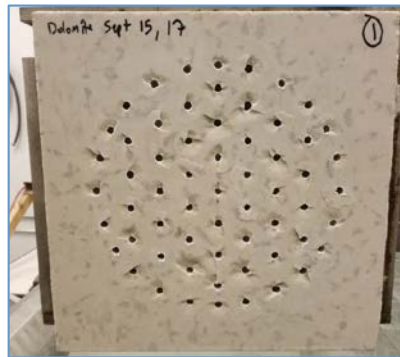
Laser Drilling 20kW in Air



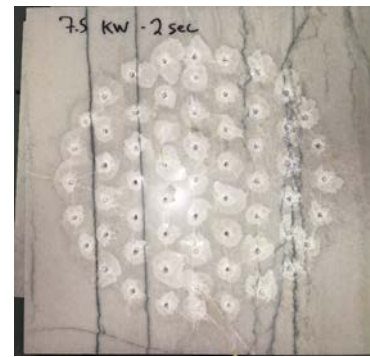


Beam Pattern & Rock Removal

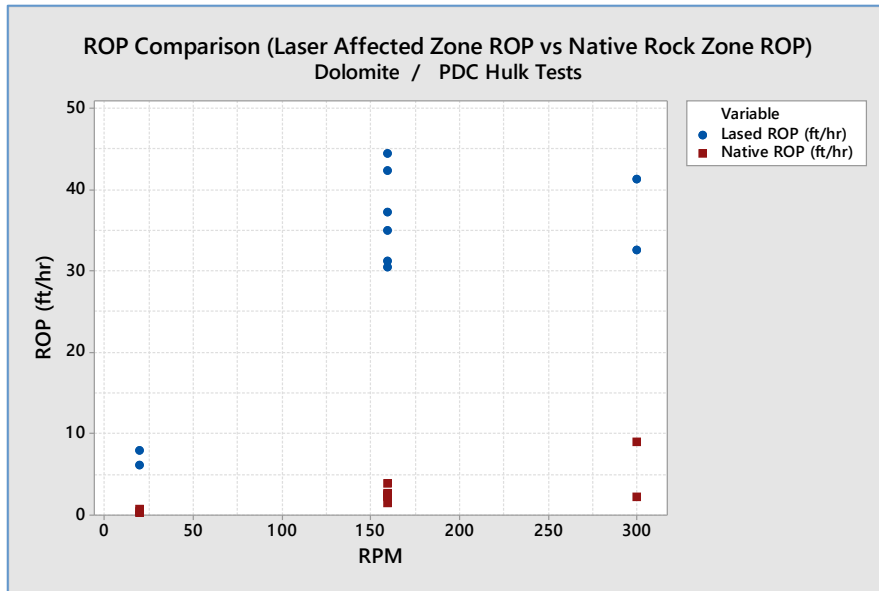
- Highly concentrated small spots instead of lines optimized for very high Watts/cm² to overcome water effects



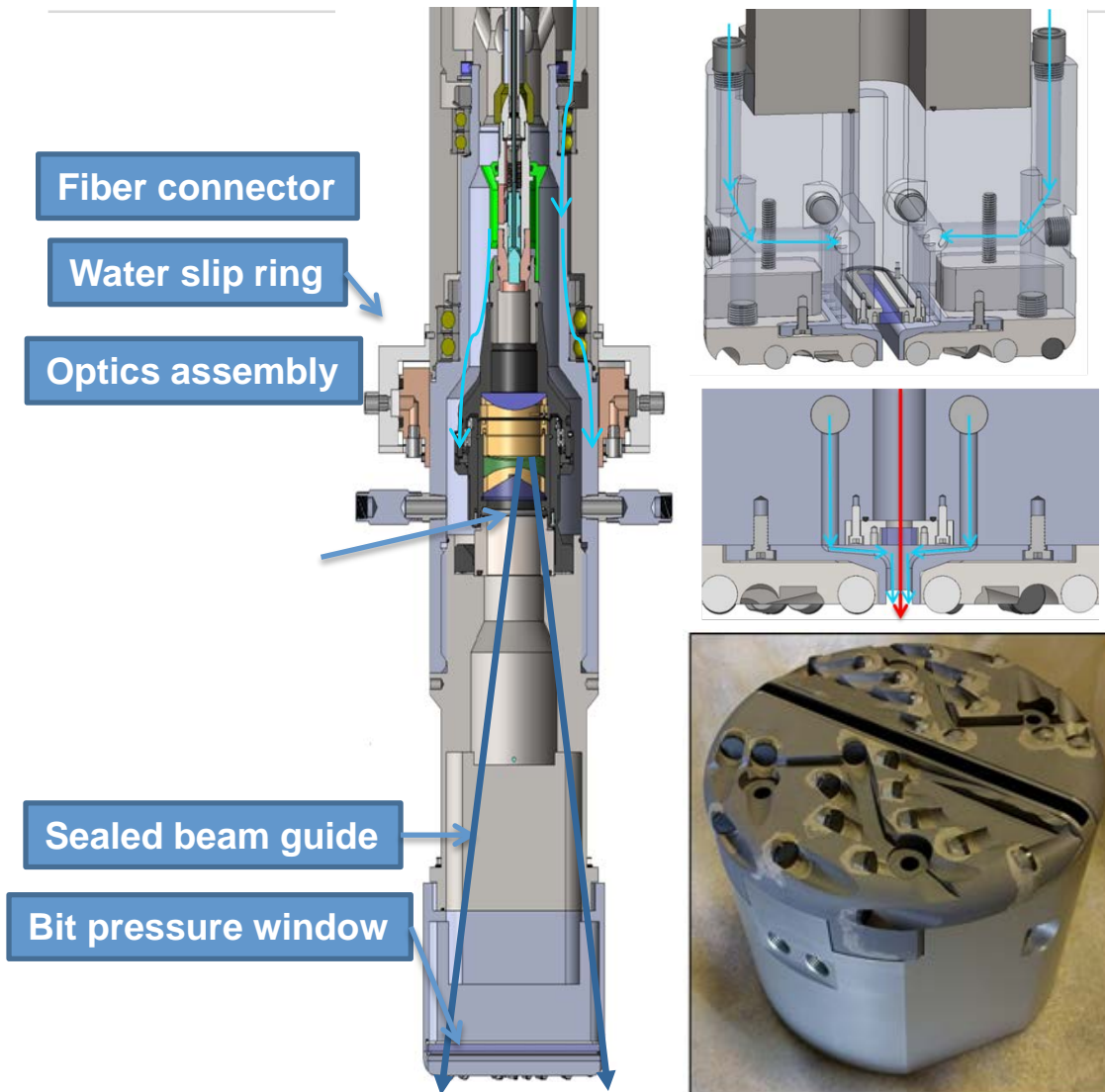
Dolomite



Quartzite



Laser Drilling – Prototype Water BHA



Final Thoughts....

Challenges



Challenges for 200m-1km depth

- Weight = cost → has to fit on launch/landing vehicle
- Reduced Gravity (1/3)
→ thrust and cuttings retrieval
- Extreme Temperatures & Radiation
- Liquidless cuttings transport?
- Embedded hard rock (meteorites)
- Steering & Instrumentation: LWD?
- Retrieving Uncontaminated samples/cores



**PLANETARY DEEP DRILL BORES
THROUGH GYPSUM ROCK DURING
ITS FIRST FIELD TESTS**

Backup Slides

CTD Experience

Schlumberger has completed more than 1,300 wells and drilled over 3,500,000 ft with Coiled Tubing

■ Alaska

- 2 CTD hybrid rigs, ~40 wells/year, 700+ wells
- 2" & 2 3/8" CT, 3"-4 1/8" OH avg 1,500ft, avg BUR 40/100ft
- TT whipstock, toe drill out, dual exits, cement Kick off
- Completion: cemented & slotted liner

■ Venezuela

- 1 CTD barge, ~50 wells/year, 400+ wells
- 2 3/8" CT, 12 1/4" OH, recently 14 3/4" OH
- Vertical wells, ~800ft – 1,600ft
- Time per well evolution: 20 days (1995), 7 days (1996), 5 days (1997)

■ UAE

- 1 UB CTD rig, ~12 wells/year, total 52 wells, project completed
- 2 3/8" CT, 3 3/4" OH multilateral avg total footage 8,700 ft/well
- Avg BUR 45/100ft, Whipstock, 2 phase fluid, barefoot completions

■ Saudi Arabia

- Currently 3 CTD rigs, ~30 wells/year, 300+ wells
 - 1 All SLB Rig + 2 XTD Rigs under BHI P. Mgmt
- HPHT 5% H₂S ~ 0.75 well/month, 2 3/8" CT, 3 5/8" OH, multilateral, avg total footage 6,500+ ft/well

