Drilling & Well Construction Considerations

Presentation during NWTRB Deep Borehole Workshop, 10/20/2015

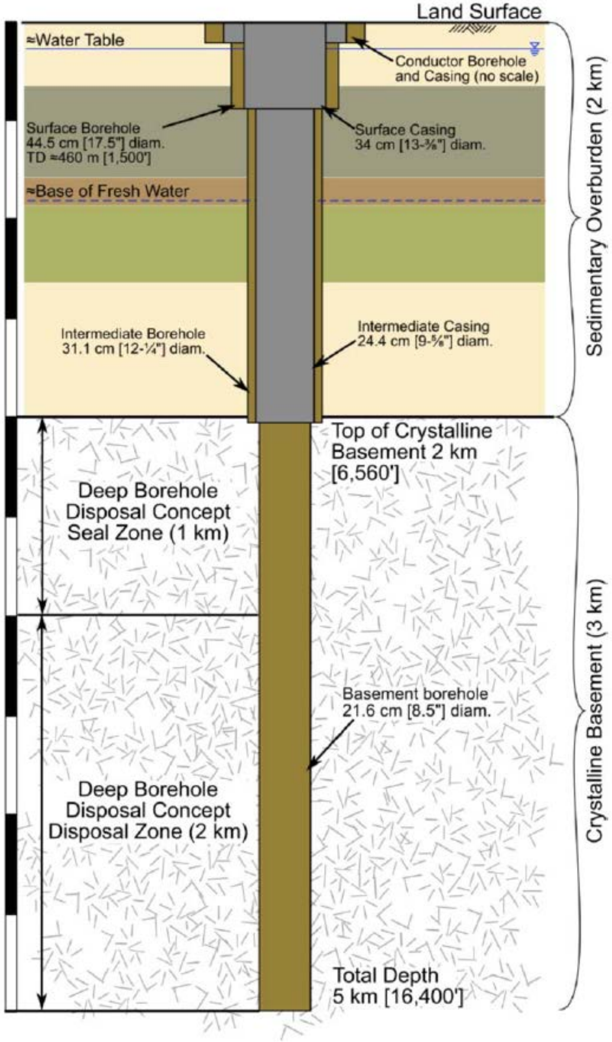
Dr. Eric van Oort
Lancaster Professor, UT Austin

THE UNIVERSITY OF TEXAS AT AUSTIN
Petroleum and Geosystems Engineering
Cockrell School

Agenda

Drilling & Well Construction Considerations

- Bits
- Drillstring Vibrations
- Vertical Directional Drilling
- Stuck Pipe
- Isolation & Abandonment



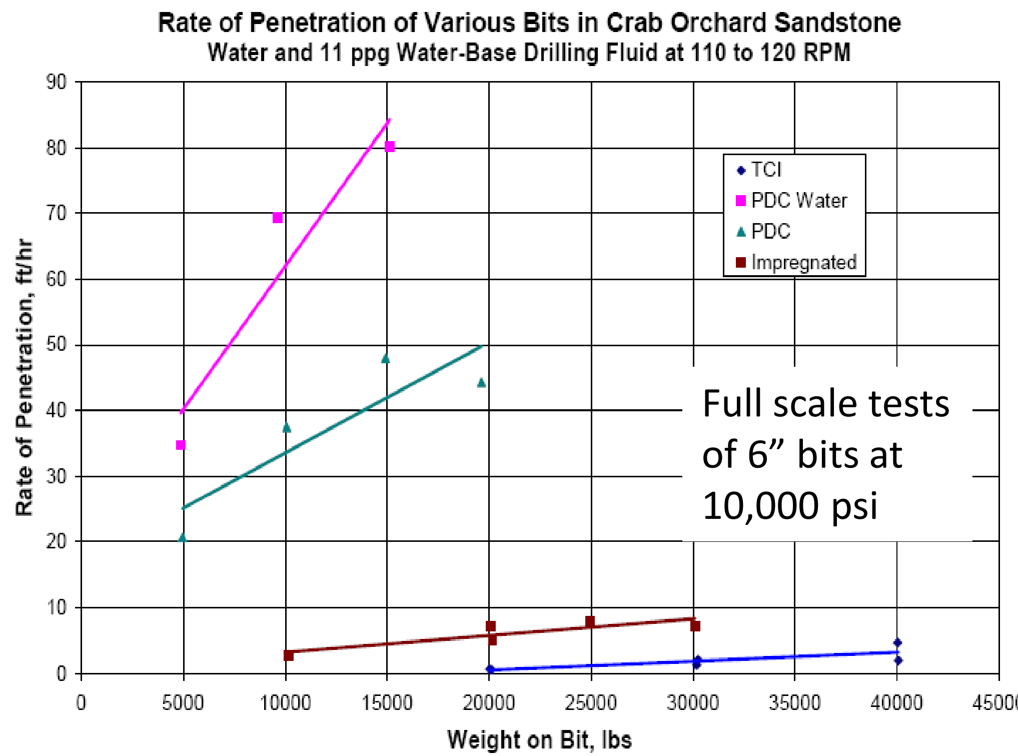
Source: Deep Borehole Field Test: Characterization Borehole Science Objectives, Kuhlman et al., 2015

Hole-Making Response by Different Bits

Polycrystalline Diamond Compact (PDC) bit

Tri-cone Rock bit with Tungsten Carbide Inserts (TCI)

Different cutting action, different ROP response



Full scale tests of 6” bits at 10,000 psi

ROP = Rate of Penetration
WOB = Weight on Bit

Source: Judzis et al., SPE/IADC 105885

Bit Selection

Formation Description	Unconfined Compressive Strength	Suitable for Milled Tooth?	Suitable for TCI ?	Suitable for PDC?	Suitable for Diamond Impreg?
Very Soft	< 4,000 psi	Yes	No*	Yes	No
Soft	4,000 – 9,000 psi	Yes	No*	Yes	No
Medium	9,000 – 15,000 psi	No	Yes	Yes	No
Hard	15,000 – 22,000 psi	No	Yes	Yes	Yes
Very Hard	> 22,000 psi	No	Yes	Possibly	Yes

*** Application of TCI is possible but would not be economically preferred**

Selection Methodology

- Consider formation hardness and eliminate unsuitable bit types
- Consider bit economics using ROP, time savings, rig costs and bit prices
- Consider the requirements of special factors such as directional requirements
- Note that the operating envelope for PDC's continues to expand

Heterogeneous Formations: Kymera Bits

Kymera (Chimaera) Hybrid Bits:

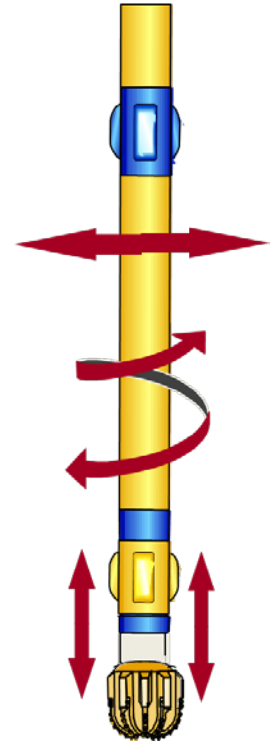
- Recently developed bits that "marry" essential features of roller cones and PDC bits
- Meant to drill in relatively large-diameter hole in medium/ hard formations (use of PDC) that are interspersed with high-strength stringers, e.g. chert (use of roller cone)

Source: Pessier and Damschen, 2010

Dynamic Dysfunctions: Vibrations

- Drilling rock is a destructive process, using heavy, high inertia drilling components that are moving at high velocities
- Some level of vibration is always present in every drilling operations
- If uncontrolled, vibration leads to dysfunction (impaired/abnormal functioning)
  - Axial Dysfunction: Bit Bounce
  - Lateral Dysfunction: Whirl (Bit and/or BHA)
  - Torsional Dysfunction: Stick-Slip
- Results of dysfunction include:
  - Low / limited ROP (wasted energy, premature bit dulling)
  - Reduced bit life, increased number of bit runs and associated trips
  - Fatigue accumulation, wash-outs and twist-offs because of cyclic stresses
  - MWD / LWD failures due to high-G shock loading
- Dynamic dysfunction is <u>the most limiting factor</u> in achieving optimum ROP and minimizing bit runs

Vibration Mode	Dysfunction
Axial	Bit Bounce
Torsional	Stick-Slip
Lateral	Bit Whirl BHA Whirl



Chaotic Whirl Vibrations

Source: Aldred, W.D. and Sheppard, M.C., "Drillstring Vibrations: A New Generation Mechanism and Control Strategies," SPE 24582

Video courtesy of Schlumberger, Inc.

Chaotic Whirl Vibrations

Source: Aldred, W.D. and Sheppard, M.C., "Drillstring Vibrations: A New Generation Mechanism and Control Strategies," SPE 24582

Video courtesy of Schlumberger, Inc.

Chaotic Whirl Vibrations

Source: Aldred, W.D. and Sheppard, M.C., "Drillstring Vibrations: A New Generation Mechanism and Control Strategies," SPE 24582

Video courtesy of Schlumberger, Inc.

Chaotic Whirl Vibrations

Source: Aldred, W.D. and Sheppard, M.C., "Drillstring Vibrations: A New Generation Mechanism and Control Strategies," SPE 24582

Video courtesy of Schlumberger, Inc.

Chaotic Whirl Vibrations

Source: Aldred, W.D. and Sheppard, M.C., "Drillstring Vibrations: A New Generation Mechanism and Control Strategies," SPE 24582

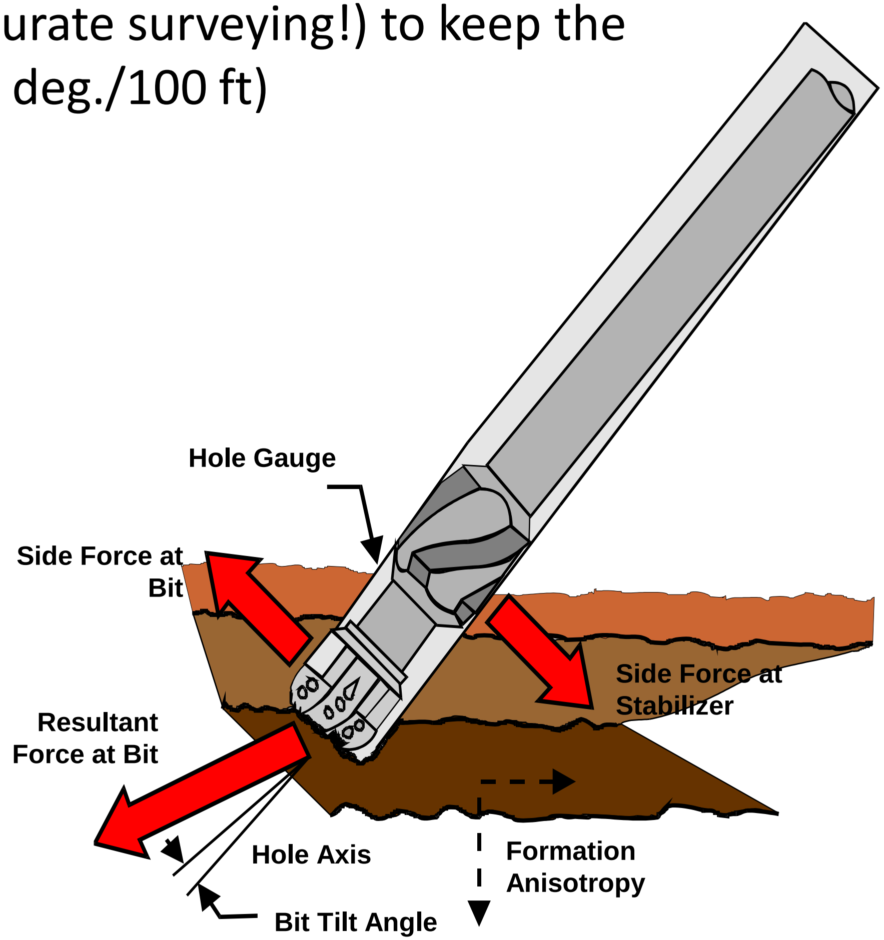
Video courtesy of Schlumberger, Inc.

Vertical Directional Drilling

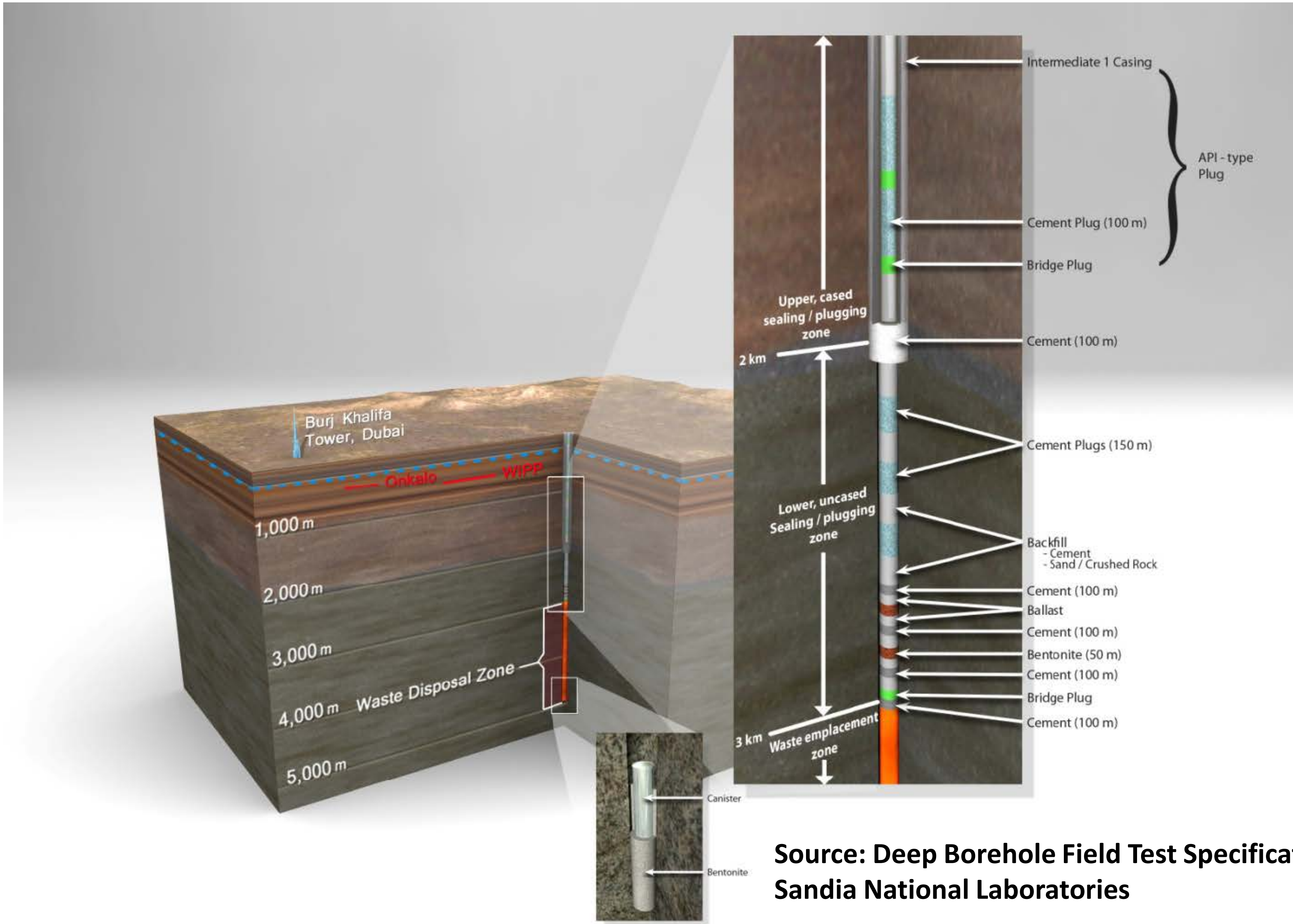
Well dogleg severity and tortuosity will need to be minimized, which will require directional drilling techniques (downhole motors/turbines, rotary steerables, accurate surveying!) to keep the well as vertical as possible (e.g. DLS < 1 deg./100 ft)

Factors affecting bit trajectory

- Gauge and placement of stabilizers
- Diameter & length of (sections of) drill collars
- Weight on bit
- Rotary speed
- Bit type & bit gauge length
- Formation anisotropy and dip angle
- Formation hardness (& tendency to wash/break out)
- Flow rate
- Rate of penetration



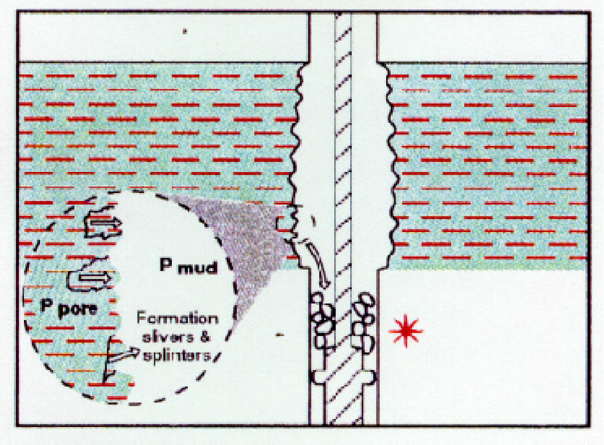
Well Construction & Abandonment



Source: Deep Borehole Field Test Specifications, Sandia National Laboratories

Stuck Pipe Mechanisms

STRESSED OR GEOPRESSURIZED FORMATIONS



CAUSE
Mud weight is insufficient to support formations at high stress or high pore pressure, or is not adjusted for hole angle increase or change in well azimuth; failed formation fragments (cavings) obstruct the annulus and jam the string on in-gauge hole sections

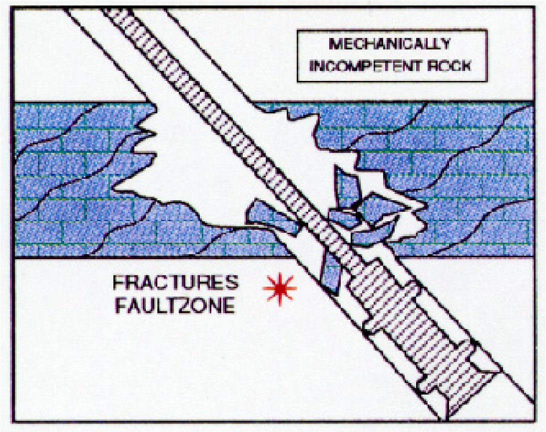
WARNINGS
- Shale cavings at the shakers
- Torque & drag increase
- Hole cleaning problems
- Increased overpulls on trips

INDICATIONS
- Possible while drilling or tripping (especially POOH)
- Hole bridged or complete pack-off possible
- Circulation may be impossible or highly restricted

ACTIONS TO FREE
- Go / jar down, circulate hole clean at maximum pump rate

AVOIDANCE
- Select appropriate mud weight / adjust mud weight
- Back ream, maximize hole cleaning
- Case off sections prone to instability
- Avoid annular pressure swabs / surges

FRACTURED & FAULTED FORMATIONS



CAUSE
Pieces of formations that are intersected by faultes or have natural / induced fractures may fall into the wellbore and jam the drillstring

WARNINGS
- Geological prognosis for fractures limestones, shales and/or the presence of faults
- Blocky cavings on shakers
- Fill on connections / trips; hole difficult to clean

INDICATIONS
- Likely on trips (POOH), possible while drilling
- Sudden, erratic torque & drag before sticking
- Circulation may be impossible or highly restricted

ACTIONS TO FREE
- Jar down with max. trip load; do not apply torque
- Attempt to circulate hole clean (use high density / high viscosity sweeps)
- Spot acid if stuck in limestone

AVOIDANCE
- Circulate hole cleanin before drilling ahead
- Minimize seepage losses and wetting of fractures
- Slow trip speeds when BHA enters suspected zone
- Case off troublesome section (use e.g. EST, STE)

"Stuck canisters" is a particular concern when running waste canisters into an open hole that is not stable or has high (local) tortuosity – it does not take much to "wedge" a canister with a caving (0.25" – 0.9" radial clearance)

Well Isolation & Abandonment

Well Abandonment considerations:

- Offshore abandonments set a high standard for abandonments in general and are recommended as a minimum for nuclear waste disposal wells (250 CFR 1712-1717 & 1721)
- Barriers will need to be explicitly evaluated and possibly monitored continuously
- How safe is an "open-hole completion" around the waste canisters?
- Cement may not be the most versatile material to use in abandonments (see next slide)
- What about potential well re-entry and intervention?

Source: 250 CFR 1715

PERMANENT WELL PLUGGING REQUIREMENTS

If you have . . .	Then you must use . . .
(1) Zones in open hole,	Cement plug(s) set from at least 100 feet below the bottom to 100 feet above the top of oil, gas, and fresh-water zones to isolate fluids in the strata
(2) Open hole below casing,	(i) A cement plug, set by the displacement method, at least 100 feet above and below deepest casing shoe;
	(ii) A cement retainer with effective back-pressure control set 50 to 100 feet above the casing shoe, and a cement plug that extends at least 100 feet below the casing shoe and at least 50 feet above the retainer; or
	(iii) A bridge plug set 50 feet to 100 feet above the shoe with 50 feet of cement on top of the bridge plug, for expected or known lost circulation conditions
(3) A perforated zone that is currently open and not previously squeezed or isolated,	(i) A method to squeeze cement to all perforations; (ii) A cement plug set by the displacement method, at least 100 feet above to 100 feet below the perforated interval, or down to a casing plug, whichever is less; or (iii) If the perforated zones are isolated from the hole below, you may use any of the plugs specified in paragraphs (a)(3)(iii)(A) through (E) of this section instead of those specified in paragraphs (a)(3)(i) and (a)(3)(ii) of this section.
	(A) A cement retainer with effective back-pressure control set 50 to 100 feet above the top of the perforated interval, and a cement plug that extends at least 100 feet below the bottom of the perforated interval with at least 50 feet of cement above the retainer;
	(B) A bridge plug set 50 to 100 feet above the top of the perforated interval and at least 50 feet of cement on top of the bridge plug;
	(C) A cement plug at least 200 feet in length, set by the displacement method, with the bottom of the plug no more than 100 feet above the perforated interval;
	(D) A through-tubing basket plug set no more than 100 feet above the perforated interval with at least 50 feet of cement on top of the basket plug; or
	(E) A tubing plug set no more than 100 feet above the perforated interval topped with a sufficient volume of cement so as to extend at least 100 feet above the uppermost packer in the wellbore and at least 300 feet of cement in the casing annulus immediately above the packer.
(4) A casing stub where the stub end is within the casing,	(i) A cement plug set at least 100 feet above and below the stub end;
	(ii) A cement retainer or bridge plug set at least 50 to 100 feet above the stub end with at least 50 feet of cement on top of the retainer or bridge plug; or
	(iii) A cement plug at least 200 feet long with the bottom of the plug set no more than 100 feet above the stub end.
(5) A casing stub where the stub end is below the casing,	A plug as specified in paragraph (a)(1) or (a)(2) of this section, as applicable.
(6) An annular space that communicates with open hole and extends to the mud line,	A cement plug at least 200 feet long set in the annular space. For a well completed above the ocean surface, you must pressure test each casing annulus to verify isolation.
(7) A subsea well with unsealed annulus,	A cutter to sever the casing, and you must set a stub plug as specified in paragraphs (a)(4) and (a)(5) of this section.
(8) A well with casing,	A cement surface plug at least 150 feet long set in the smallest casing that extends to the mud line with the top of the plug no more than 150 feet below the mud line.
(9) Fluid left in the hole,	A fluid in the intervals between the plugs that is dense enough to exert a hydrostatic pressure that is greater than the formation pressures in the intervals.
(10) Permafrost areas,	(i) A fluid to be left in the hole that has a freezing point below the temperature of the permafrost, and a treatment to inhibit corrosion; and
	(ii) Cement plugs designed to set before freezing and have a low heat of hydration.
(11) Removed the barriers required in §250.420(b)(3) for the well to be completed	Two independent barriers, one of which must be a mechanical barrier, in the center wellbore as described in §250.420(b)(3) once the well is to be placed in a permanent or temporary abandonment.

Plugs using Self Healing Materials

- Traditional Portland cement has many drawbacks:
  - It is sensitive to mud and formation fluid contamination
  - It does not bond particularly well to formations, particularly those that are clay-rich due to high-alkalinity, lime-based chemistry
  - It has low tensile strength
  - When (micro-)annuli, cracks or fractures are formed, Portland has no ability to re-heal them after its set time period
  - New materials should be explored – and are becoming available – that overcome many of these problems and are self-healing

Self Healing Cement → 3 day compressive strength = 1100 psi @ failure → Failed sample retested at 21 days = 1200 psi

Conclusions and Recommendations

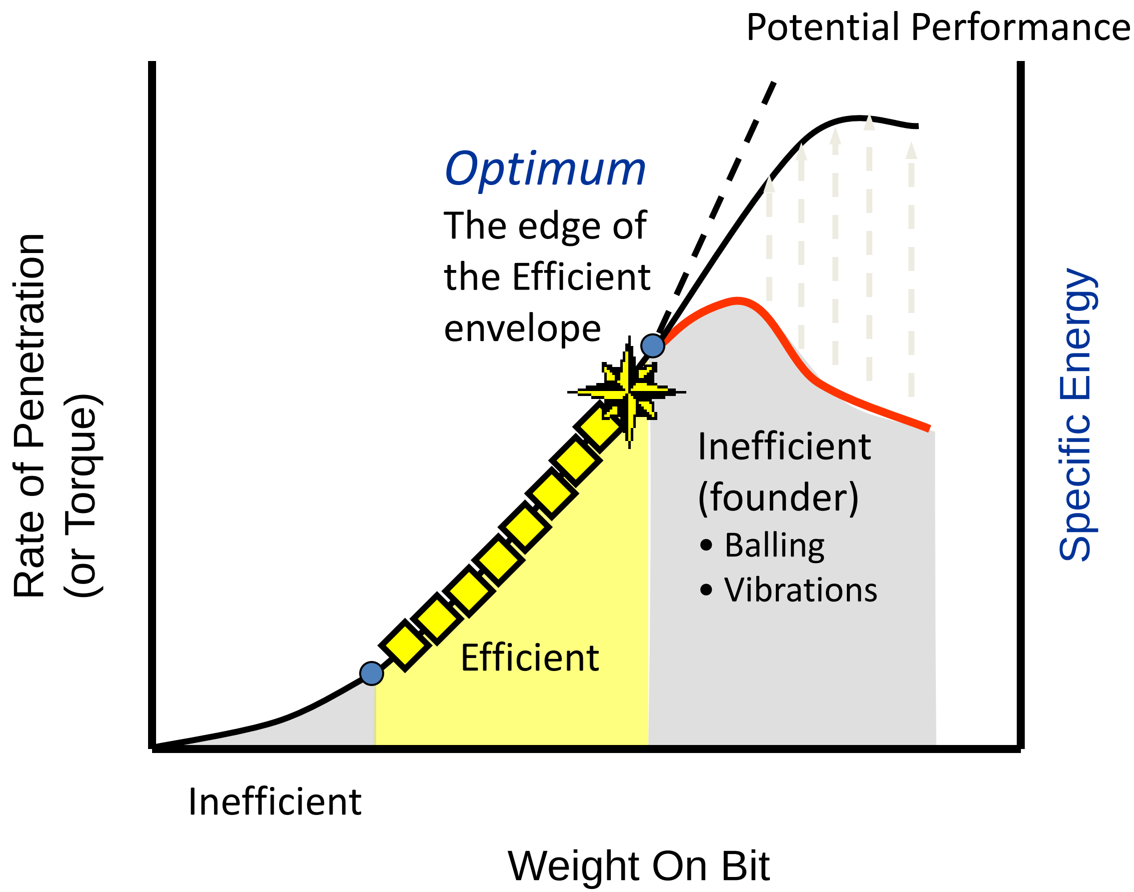
- The project needs a more detailed drilling program!
- The project would benefit technically and economically from bit-expertise and consideration of the latest in bit developments
- Harmful drillstring vibrations should be monitored (with downhole accelerometers and surface MSE) and mitigated
- Borehole quality, tortuosity and gauge are very important, and will require vertical directional drilling and excellent surveying techniques (e.g. continuous gyro)
- Stuck canister risk may exist in an unstable open hole or tortuous hole with high local dogleg severity, requiring risk mitigation
- Well abandonment and barrier installation / monitoring should be executed to the highest possible standard
- Self-healing alternatives of Portland cement should be explored for use in abandonment

Q & A

The University of Texas at Austin

Optimum Drilling Beyond *Efficient* Drilling

Performance enhanced by redesigning to extend founder point



MSE Equation

$$E_s = \frac{W}{A_b} + \frac{120\pi T N}{P A_b}$$

In the Efficiency envelope the torque/ROP ratio is nearly constant, so MSE is nearly constant

Optimum drilling is at the edge of the Efficiency envelope

Source: Dupriest and Koederitz, "Maximizing Drill Rates with Real-Time Surveillance of Mechanical Specific Energy," SPE/IADC 92194