Downhole Navigation for Oil & Gas Drilling

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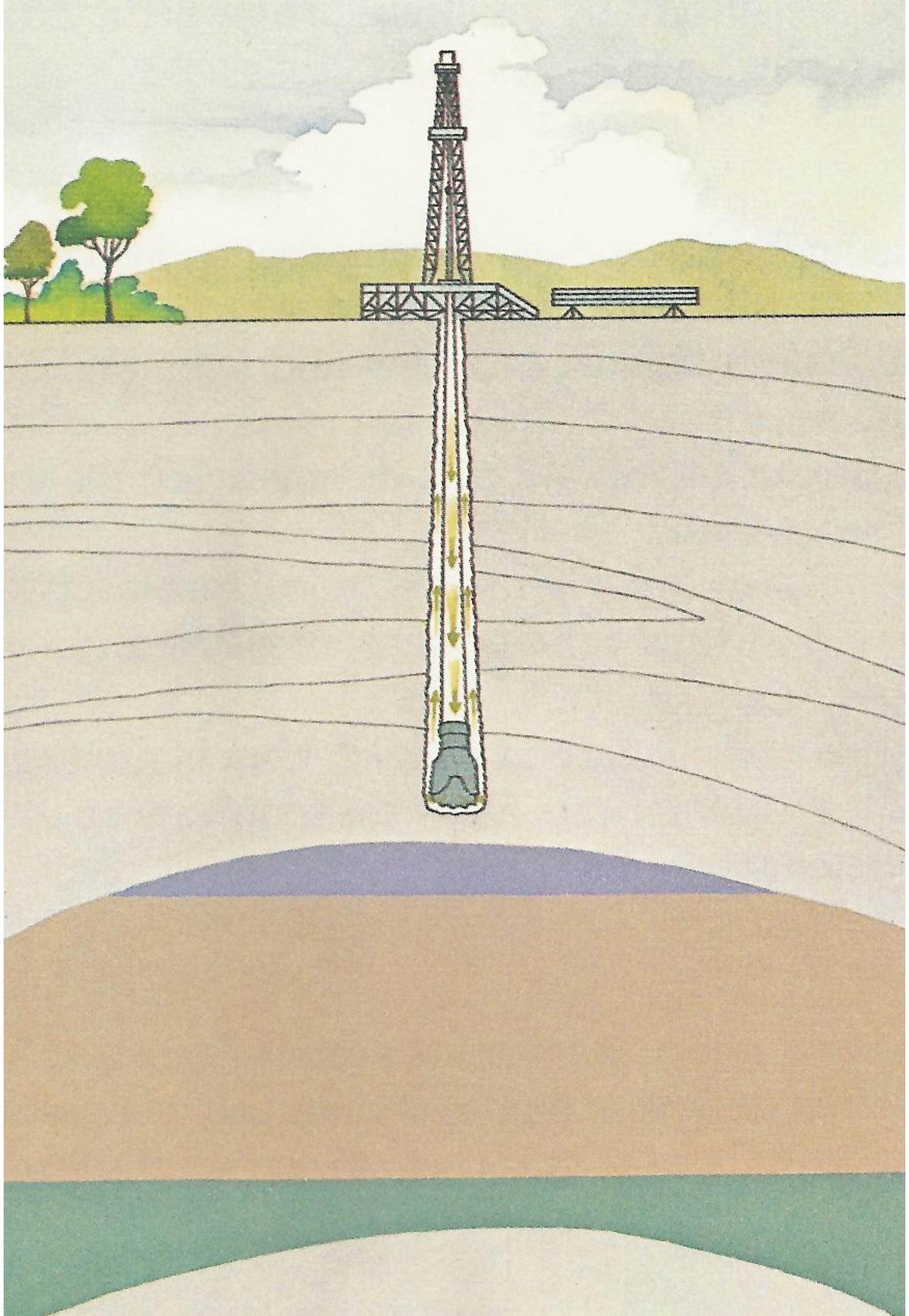
Outline

- Importance of Accurate Directional Drilling
- Basic D & I Methods
- Hardware Requirements
- “GeoSteering” the Well
- (Drilling Kinematics)

Oil Well Drilling



Why Directional Drilling?

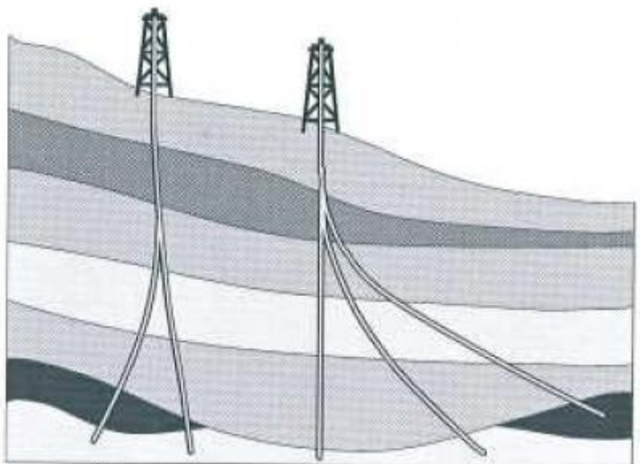


Figure 1-5 Multiple exploration wells from a single well bore.

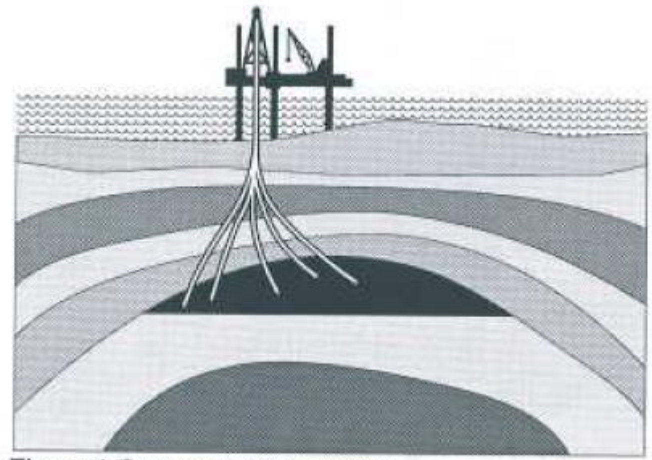


Figure 1-7 Offshore multiwell drilling.

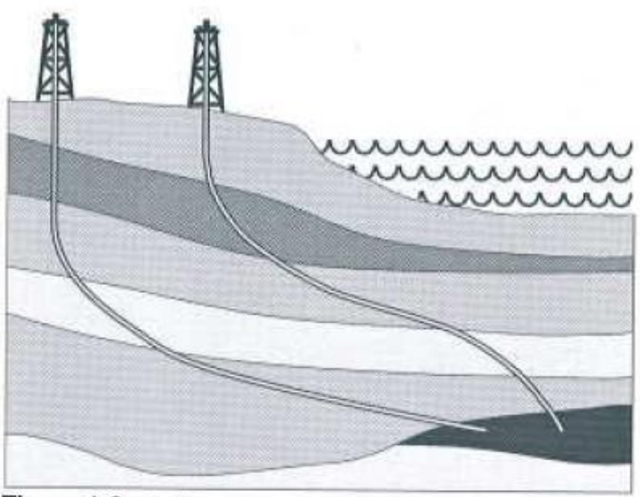


Figure 1-6 Onshore drilling.

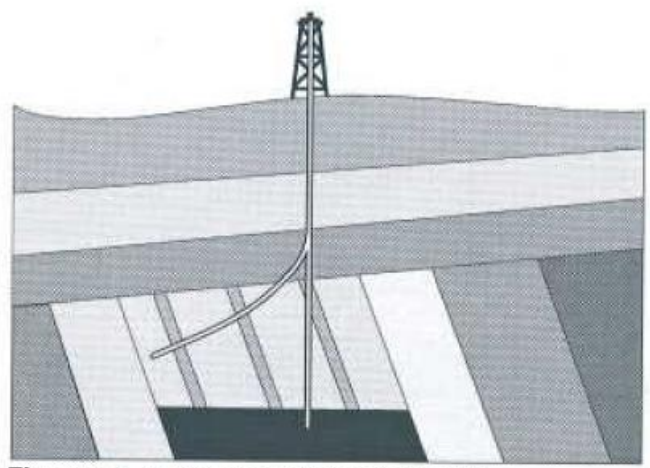


Figure 1-8 Multiple sands from a single well bore.

Why Directional Drilling?

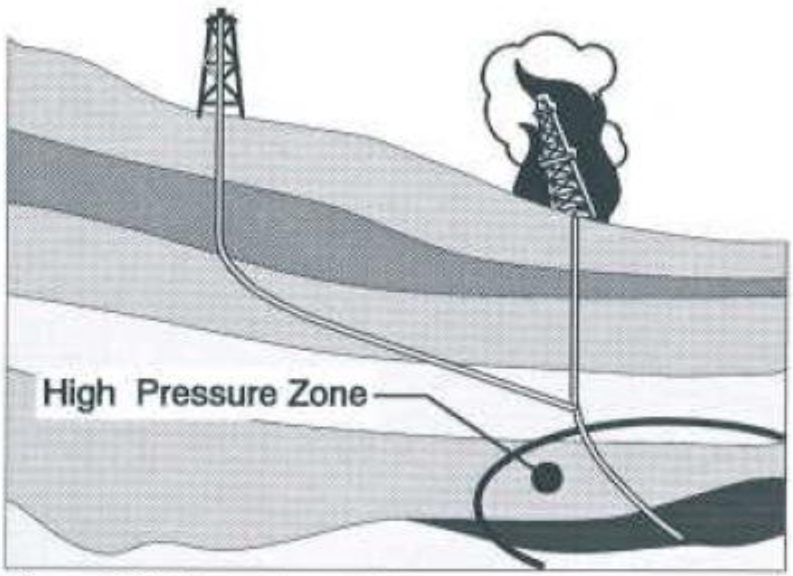


Figure 1-9 Intercepting a high pressure zone.

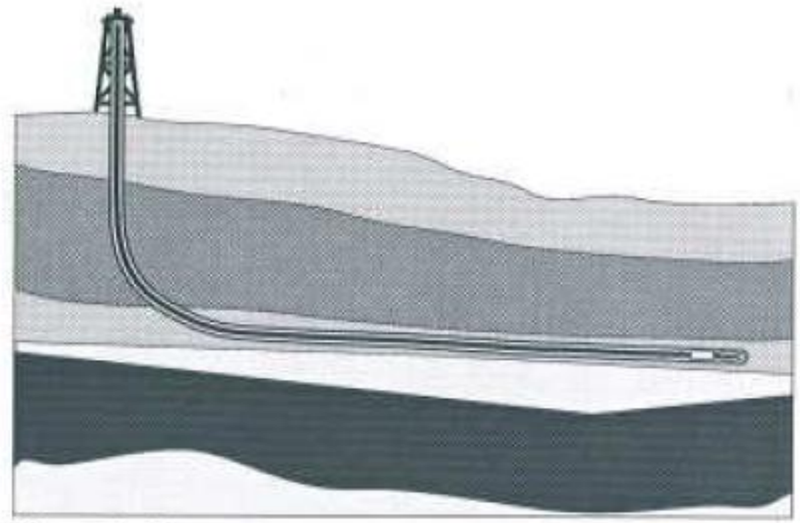
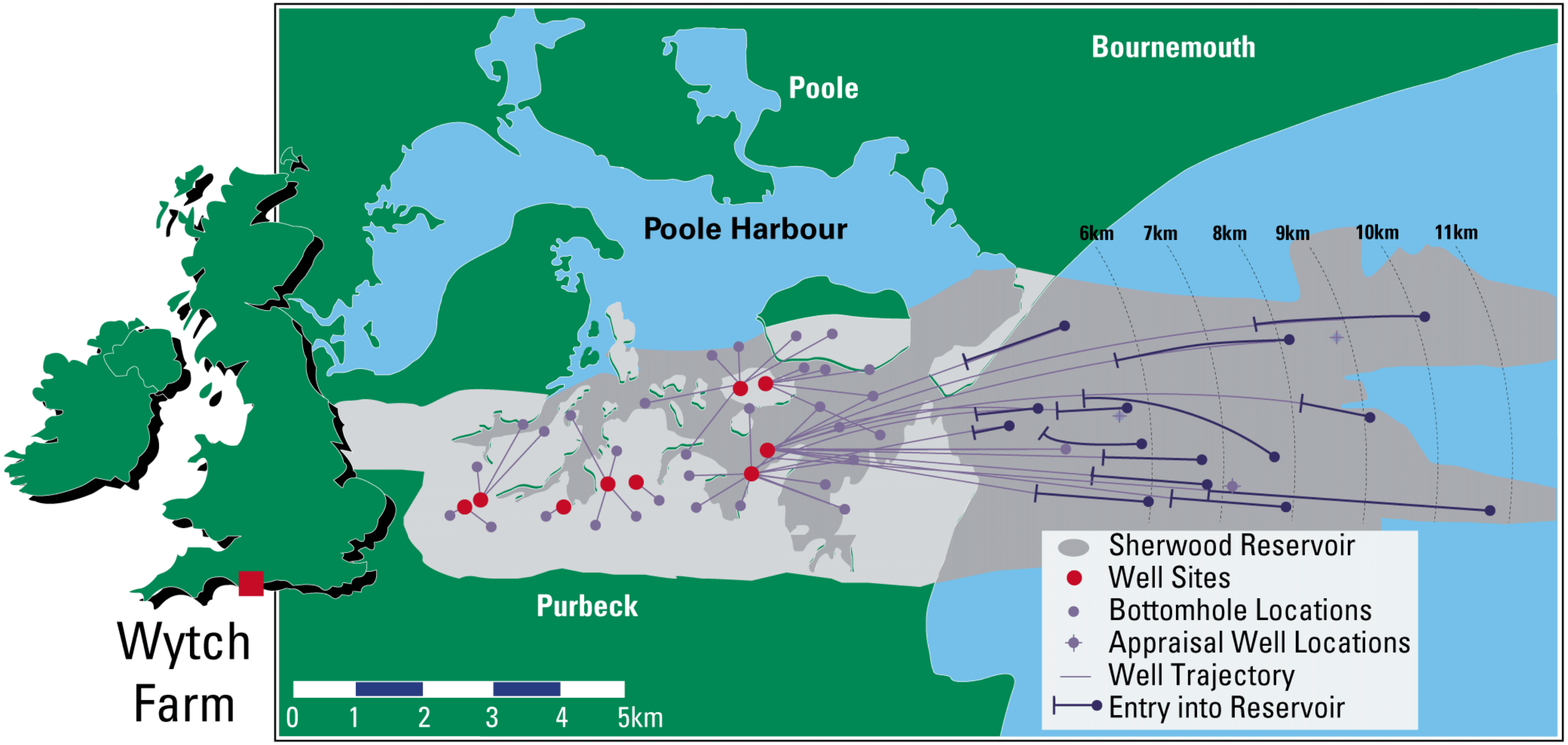
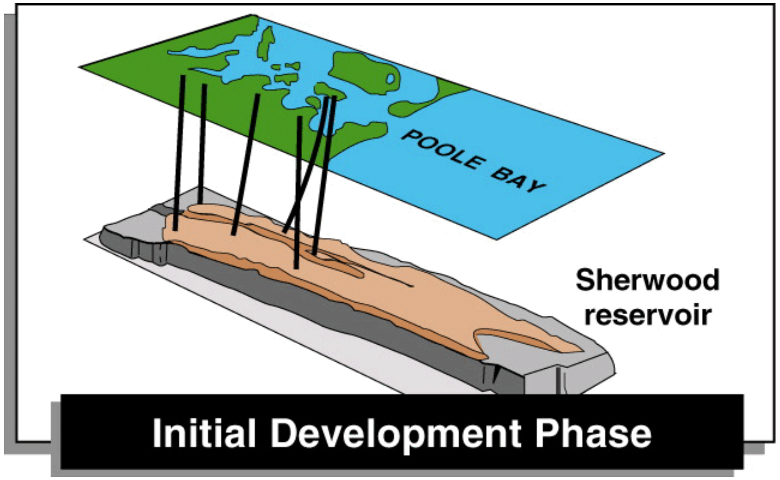


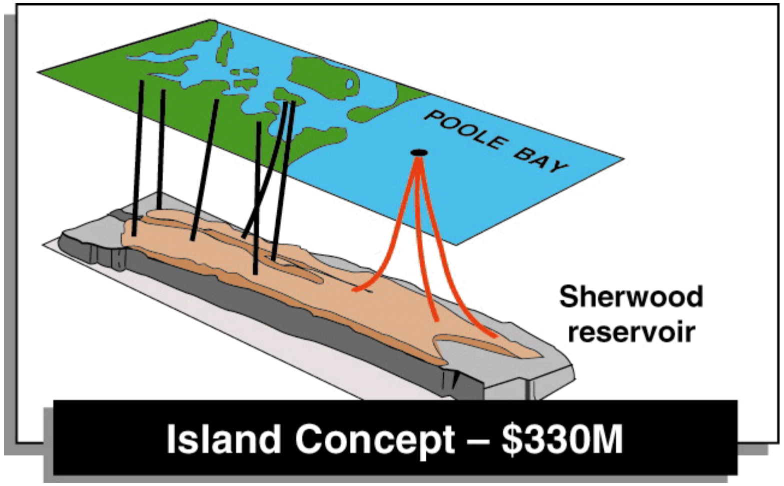
Figure 1-10 Horizontal wells.

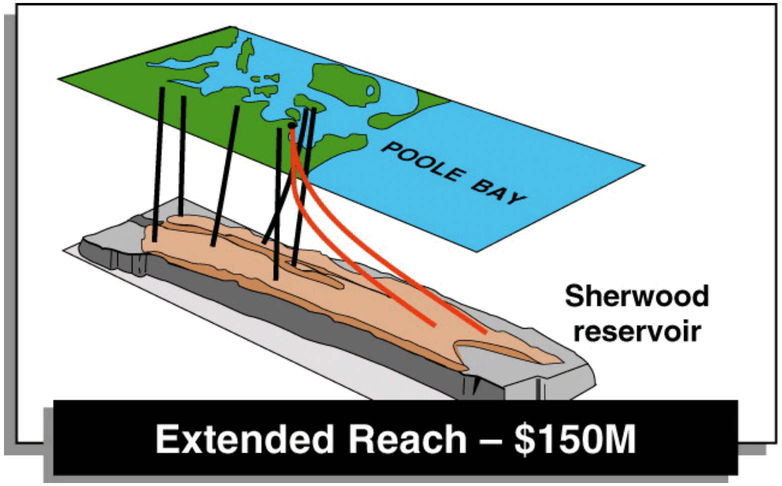
Extended Reach Drilling (ERD)



Wytch Farm ERD



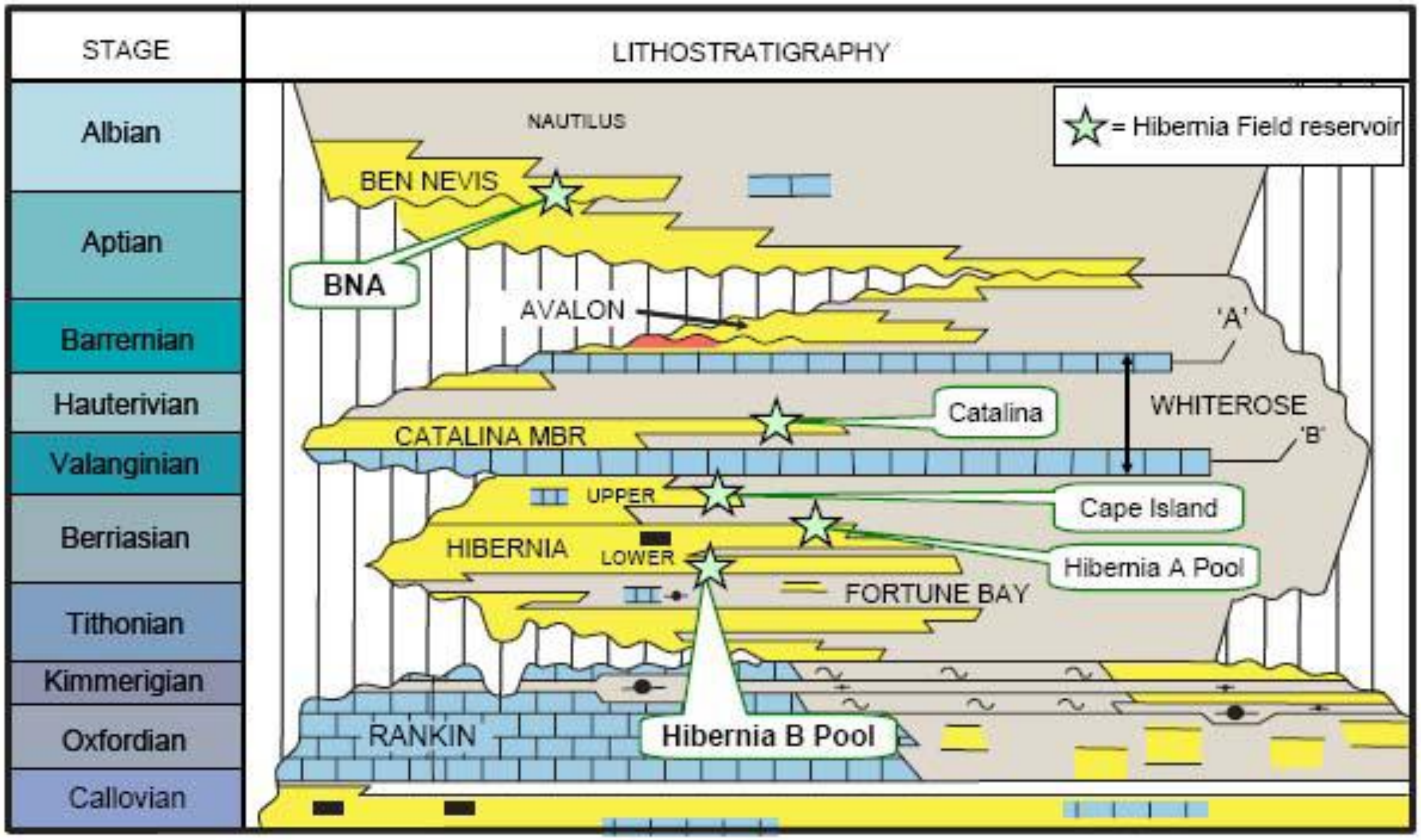




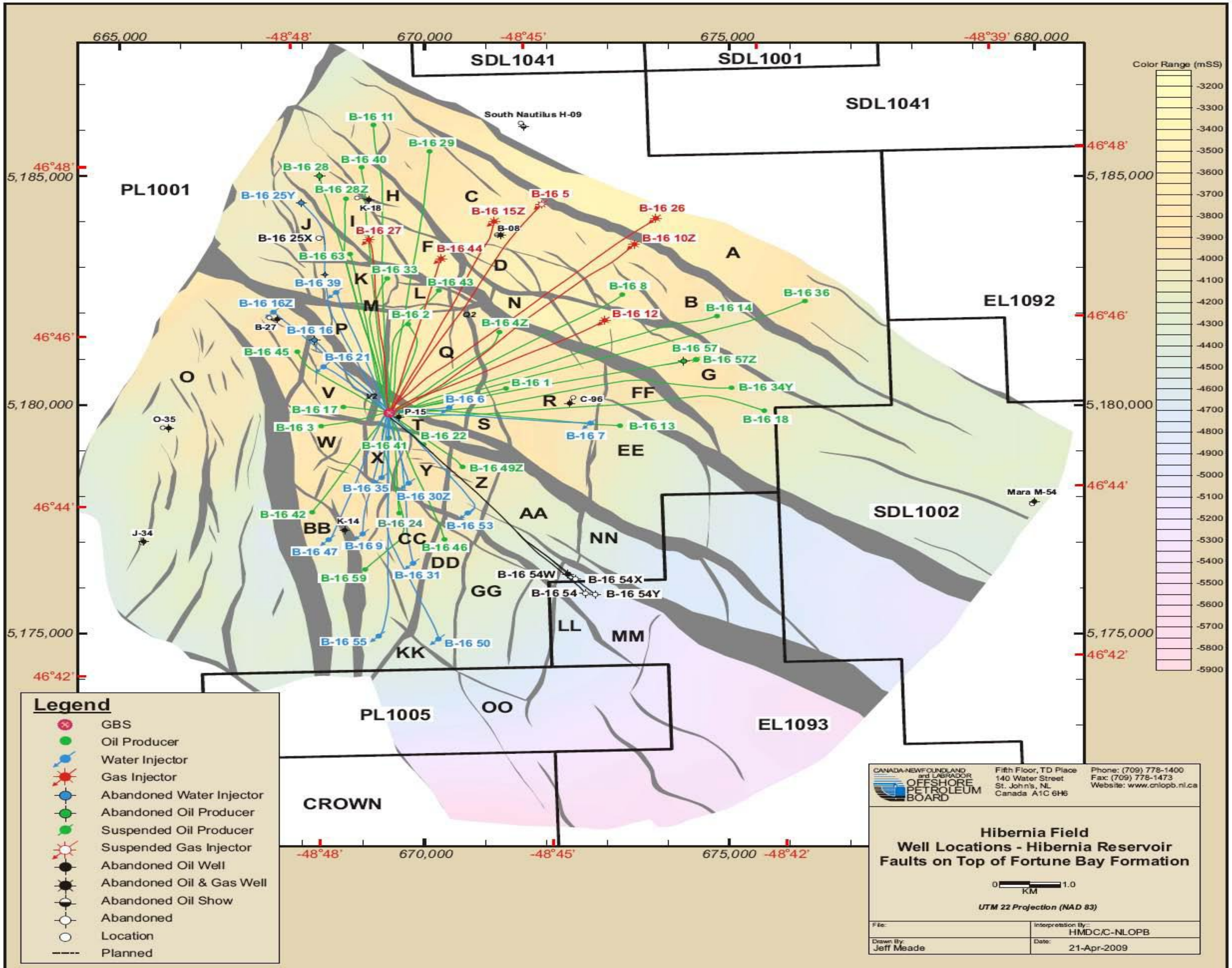
Hibernia Platform, E. Canada

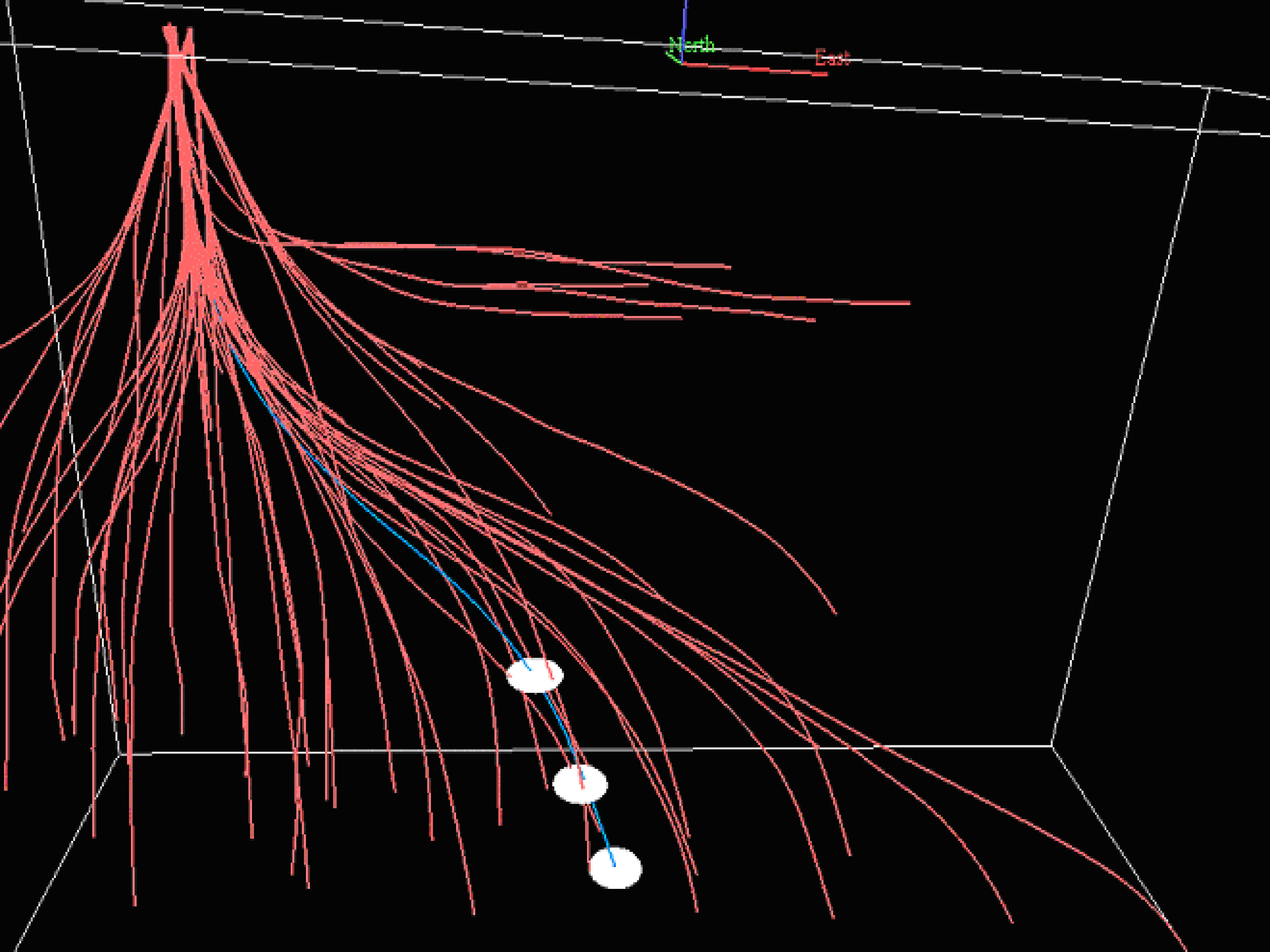
- Gravity Base Structure
- Platform Weight - 1.2 million tonnes
- Platform Height - 224 metres
- Drilling Derricks - 72m high
- Hp Mud System - 51.7MPa (7500psi) pumps downrated to 41.4MPa (6000psi)
- Top Drive-Varco TDS rated for 83 kN-m

Hibernia Field, E. Canada

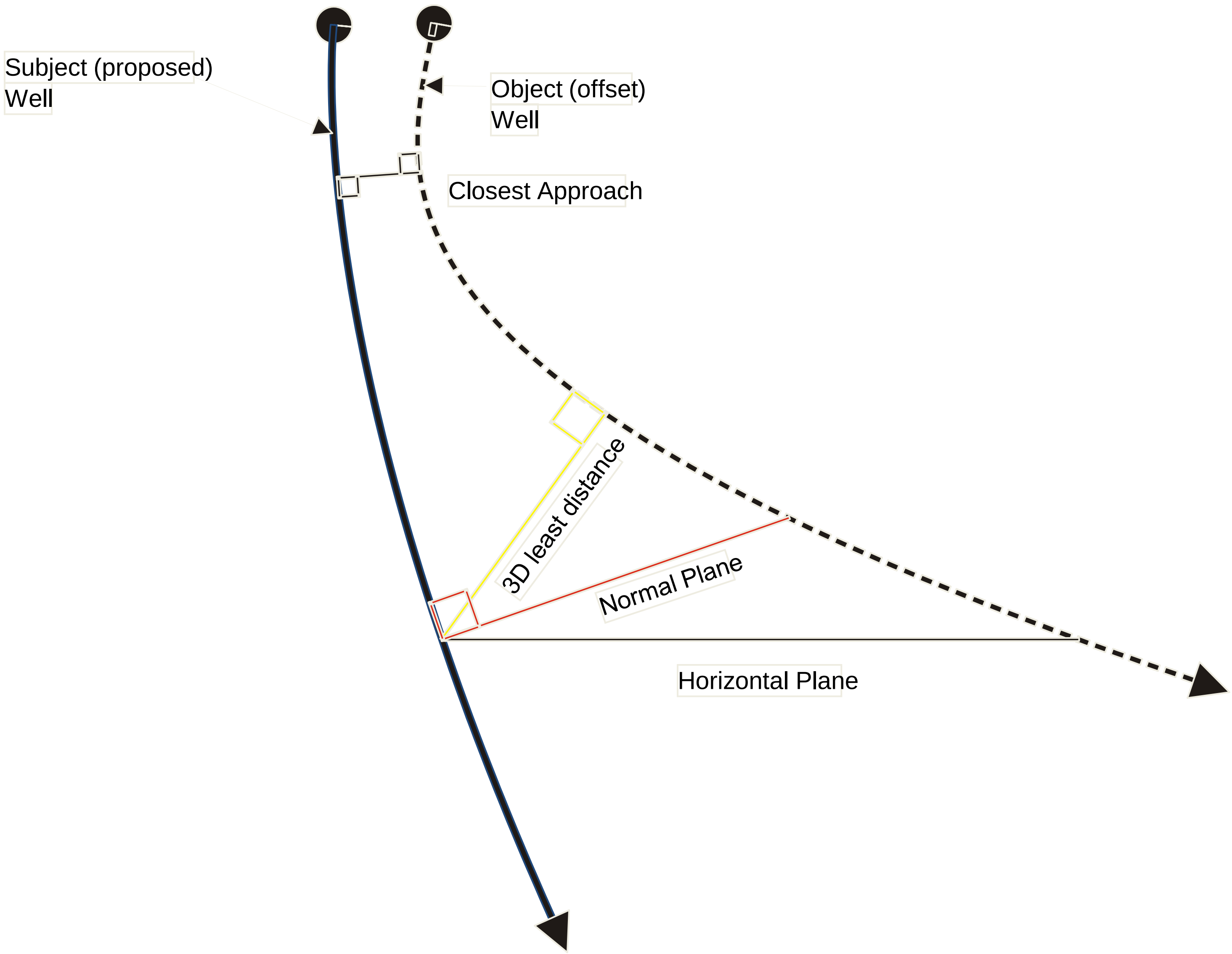


Hibernia Field, E. Canada

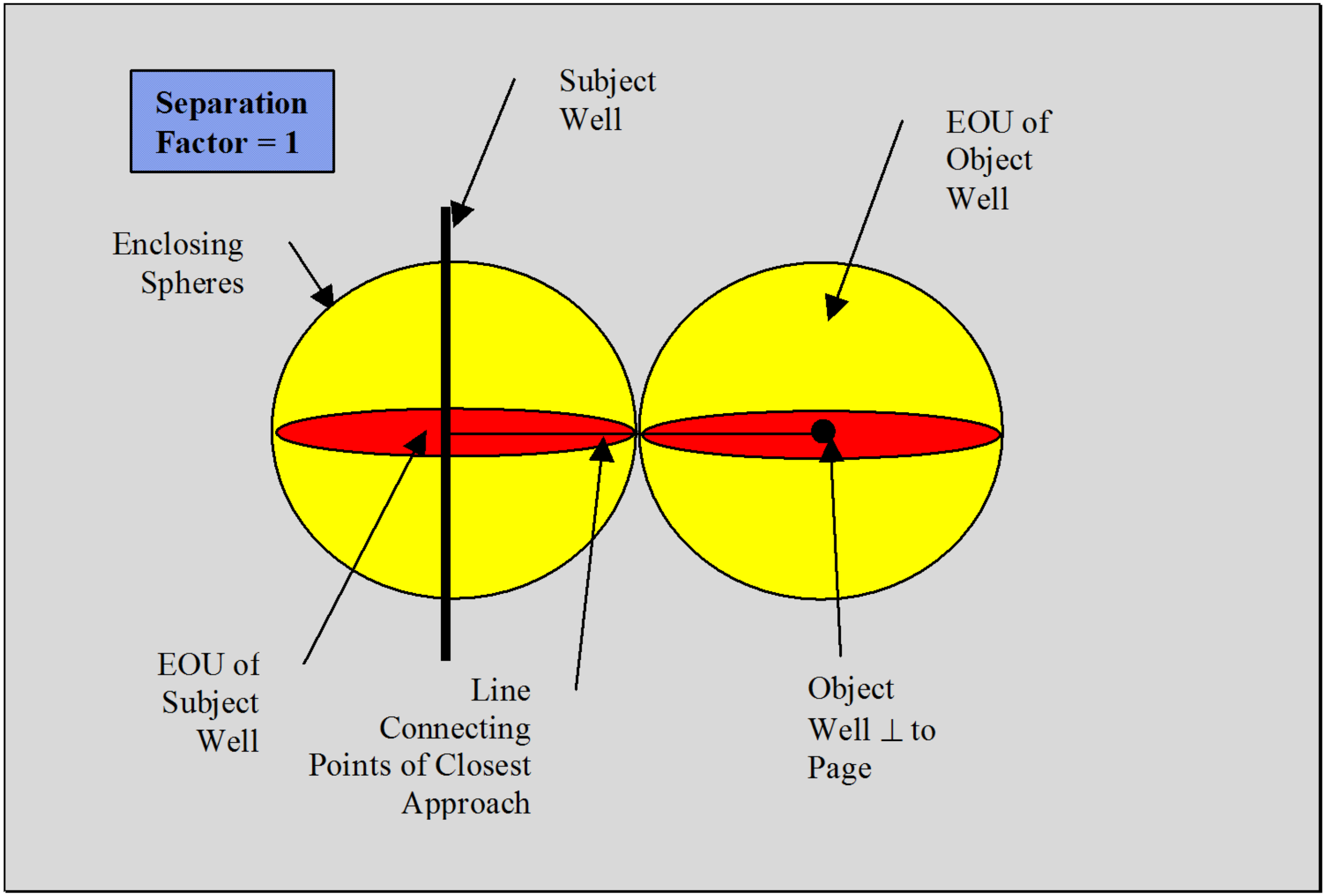



North
East

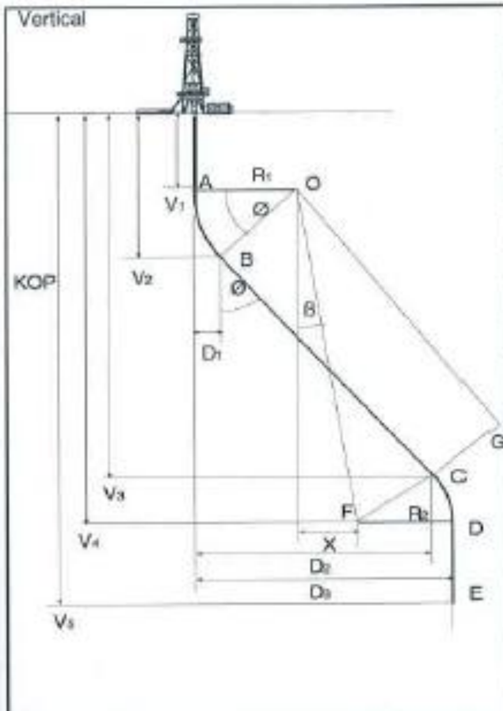
Analysis Methods



Separation Factor = 1



Basic Geometrical Well Plan



CALCULATIONS

	VERTICAL DEPTH	HORIZONTAL DISPLACEMENT	MEASURED DEPTH
KICK-OFF POINT KOP	V_1		
END OF BUILD	V_2	D_1	
START DROP	V_3	D_2	
END DROP	V_4	D_4	
TARGET	V_5	D_5	

MAX. INCLINATION	Ø
BUILD UP RATE BUR	BUR = °/100 / 100 FT =
DROP OFF RATE DOR	DOR = °/100 / 100 FT =

RADII OF CURVATURE. $R_1 = \frac{180}{BUR \times \pi}$ =

$R_2 = \frac{180}{DOR \times \pi}$ =

Line $X = D_3 - (R_1 + R_2)$ X = ______

Angle $B = \tan^{-1}\left(\frac{X}{V_4 - V_1}\right)$ B = ______°

Line $OF = \frac{V_4 - V_1}{\cos B}$ OF = ______

Line $OG = \sqrt{OF^2 - (R_1 + R_2)^2}$ = ______

Angle $FOG = \sin^{-1}\left(\frac{R_1 + R_2}{OF}\right)$ = ______°

Angle Ø = Angle FOG + B $R_1 + R_2 < D_3$

Ø = ______°

End of Build

Measured depth $= V_1 + \frac{Ø}{BUR}$

Vertical depth, $V_2 = V_1 + R_1 \sin Ø$

Displacement, $D_1 = R_1 (1 - \cos Ø)$

Start of Drop

Measured depth $= V_1 + \frac{Ø}{BUR} + OG$

Vertical depth, $V_3 = V_2 + OG \cos Ø$

Displacement, $D_2 = D_1 + OG \sin Ø$

End of Drop

Measured depth $= V_1 + \frac{Ø}{BUR} + OG + \frac{Ø}{DOR}$

Vertical depth $= V_4$

Displacement $= D_3$

∂ = Direction to Target

$D_3 = \frac{E \text{ or } W}{\sin \partial}$

$\partial = \tan^{-1} \frac{E \text{ or } W}{N \text{ or } S}$

Declination

	N/S	E/W
GRID Rig		
GRID Tgt		

Figure 3-7 Worksheet for calculating an "S" type well where sum of Radius of Build and Radius of Drop is less than total displacement of the target.

What is Wellbore Surveying?

- Statement of the position (North, East and Down coordinates) of a wellbore relative to a given reference point.
- Reference point might be the wellhead, a defined point on a drilling platform or a defined point in an oilfield.

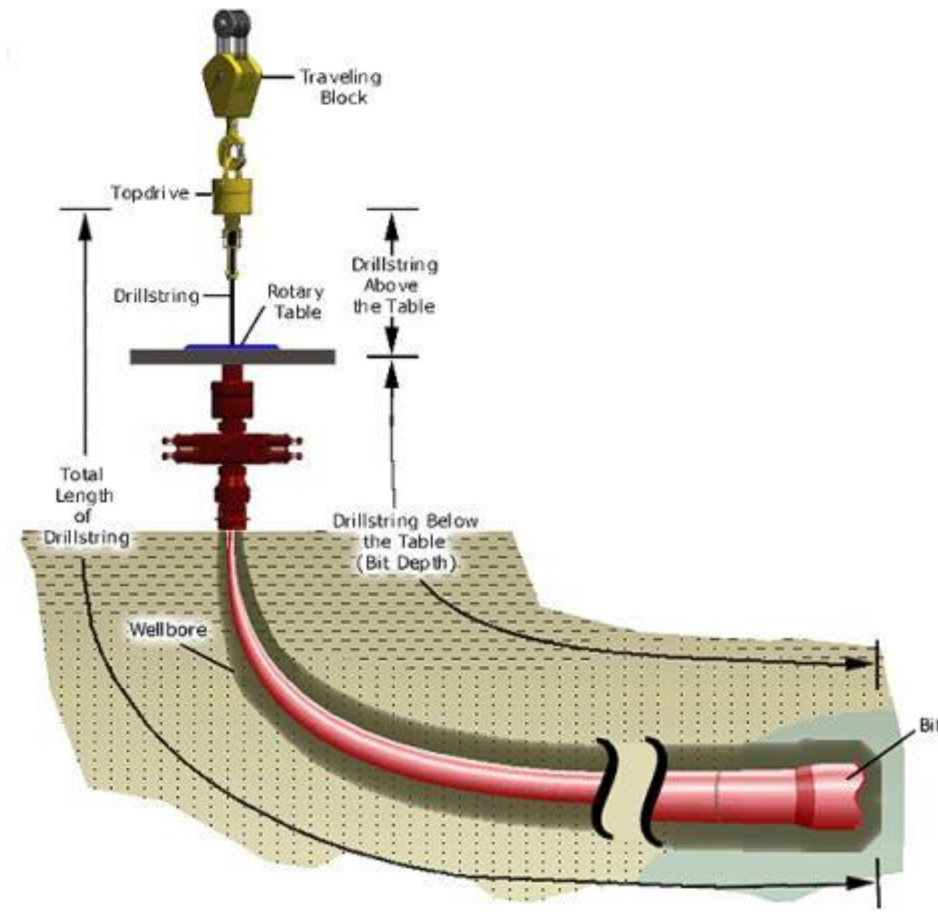
Why Do We Care About Wellbore Surveying?

- Need to steer wells to geologic targets
- Avoid other wells
- Respect lease lines
- Record well position for future use
  - Collision avoidance while drilling subsequent wells
  - Blowout contingency

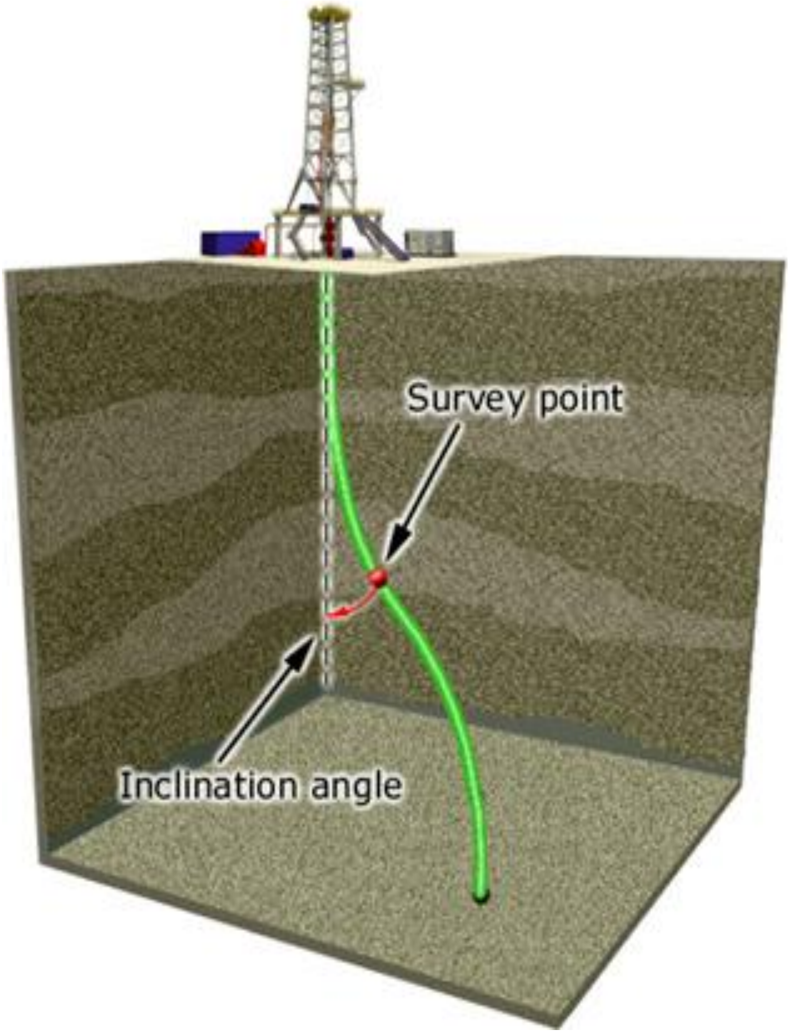
Basic D&I Concepts

- MD = Measure Depth
- TVD = True Vertical Depth

- Bit Depth
- Hole Depth
- Driller's Depth
- Survey Depth / Sensor offset
- TD = Total Depth



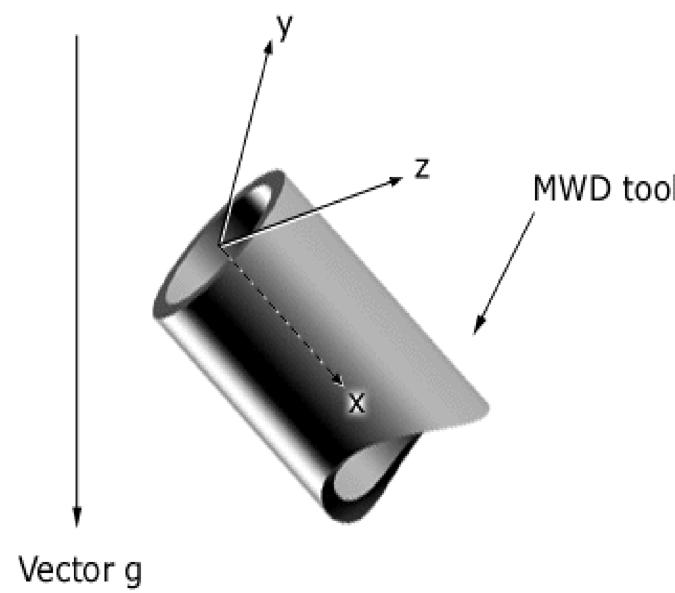
Inclination



1. The angle between Tool Axis and Gravity vector.
2. Measured by Tri-Accelerometers in MWD Tools (in degrees.)

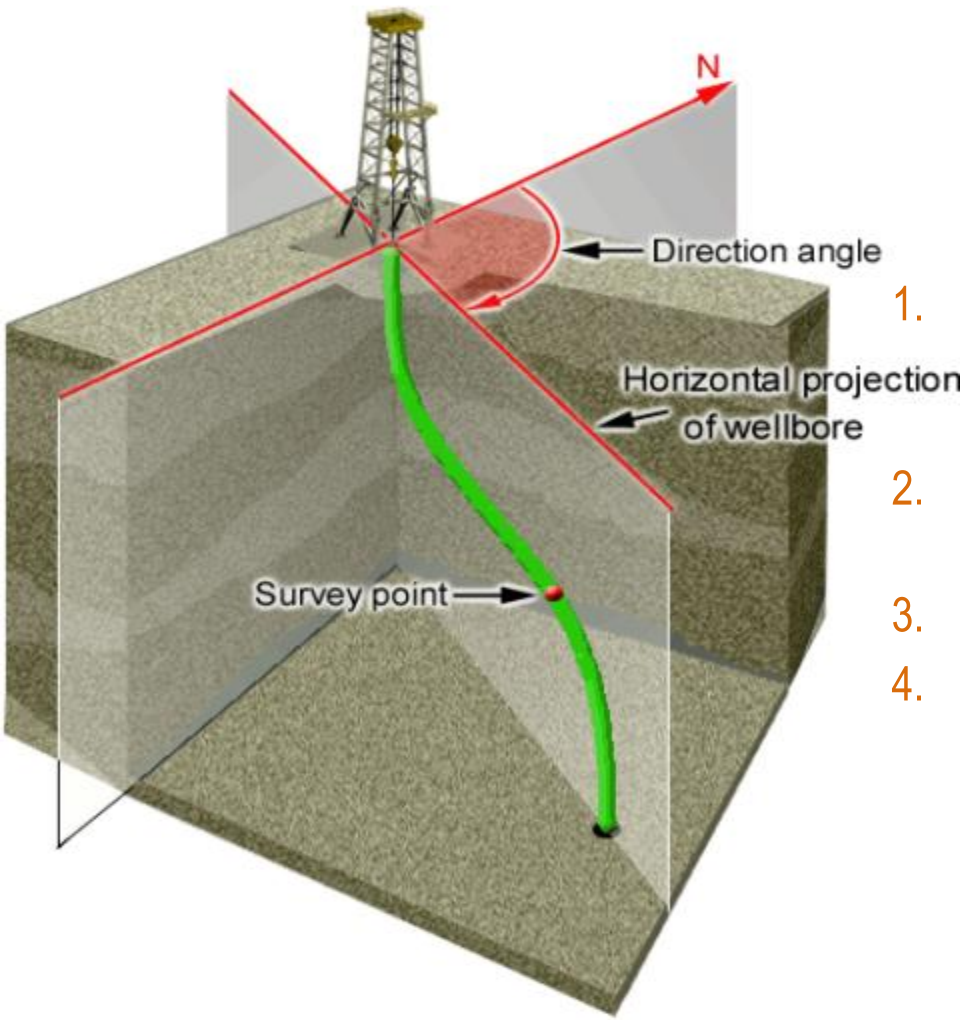
Tri-Axial Accelerometers

- Tri-Axial Accelerometers
  - Each of the 3 accelerometer sensors reads some value of the Vector G.
  - Together, they are called the orthogonal set.
  - The sum of the 3 measurements equals total Vector g (GFH).



$$GFH = \sqrt{Gx^2 + Gy^2 + Gz^2}$$

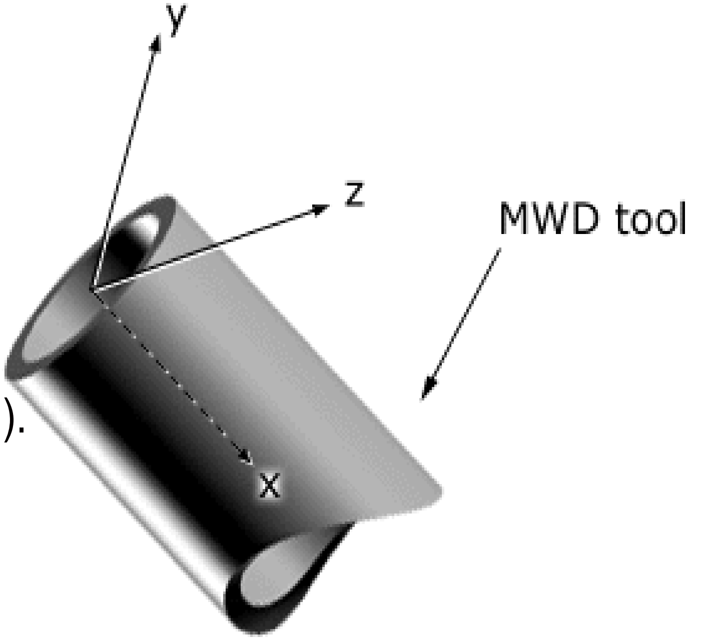
Azimuth



1. The angle between **North Reference** and a horizontal projection of current survey position (Tool Axis Vector)
2. Measured by Tri-Axial Magnetometers in MWD Tools (in degrees.)
3. Troublesome Measurement
4. True North/Magnetic North/Grid North

Tri-Axial Magnetometers

1. Each of the 3 magnetometer sensors reads some value of the Vector H.
2. Together, they are called the orthogonal set.
3. The sum of the 3 measurements equals total Vector H (HFH).

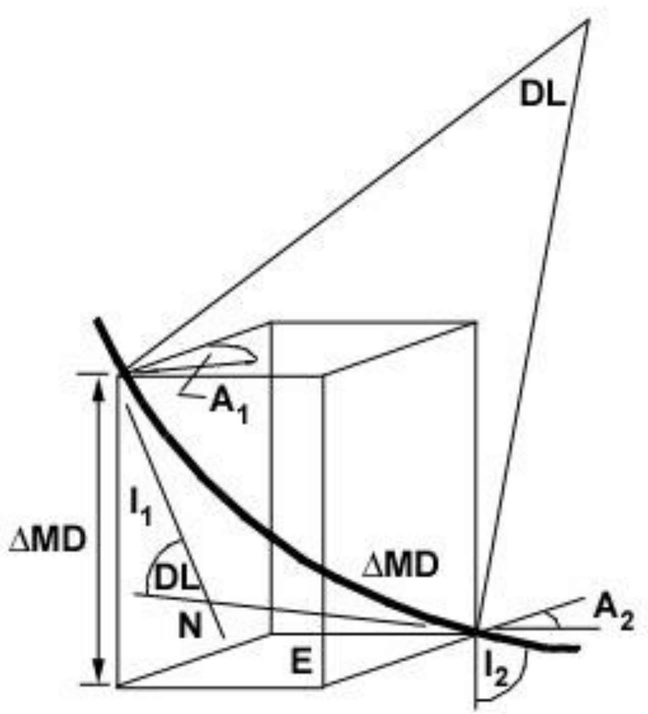


$$HFH = \sqrt{Hx^2 + Hy^2 + Hz^2}$$

Survey Calculation Methods

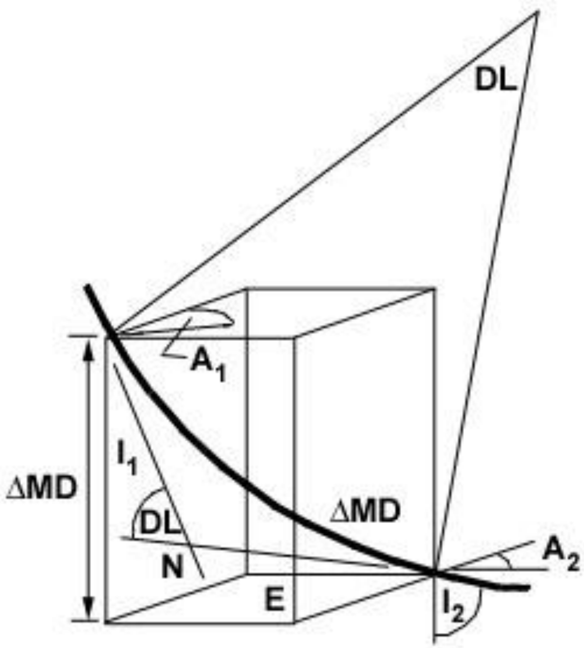
1. Tangential
2. Average angle
3. Radius of curvature
4. Minimum curvature

Minimum Curvature Method



- Assumption:
- *The Curve between two survey stations is smooth line on a sphere.*
- Feature:
  - *Using a ratio factor defined by the curvature of the wellbore section*
  - *DLS is constant through any section*
  - *BR and TR are not constant.*
  - *Most accurate and common method used today (IDEAL,MAXWELL,DOX)*

Minimum Curvature Method



- Dogleg is calculated using the following formula:

$$RF = \frac{360}{DL \cdot \pi} \tan \frac{DL}{2} \quad \text{or} \quad RF = \frac{360}{DL \cdot \pi} \cdot \frac{1-\cos DL}{\sin DL}$$

$$\Delta North = \frac{\Delta MD}{2} \cdot (\sin I_1 \cos A_1 + \sin I_2 \cos A_2) \cdot RF$$

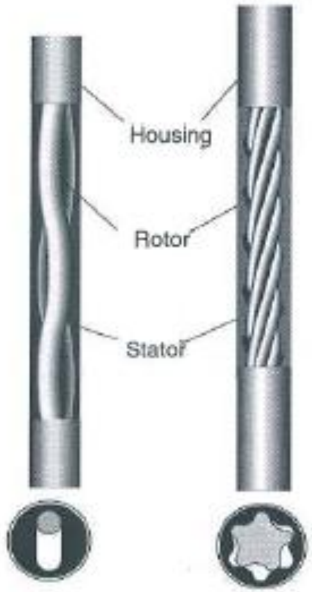
$$\Delta East = \frac{\Delta MD}{2} \cdot (\sin I_1 \sin A_1 + \sin I_2 \sin A_2) \cdot RF$$

$$\Delta TVD = \frac{\Delta MD}{2} \cdot (\cos I_1 + \cos I_2) \cdot RF$$

$$\Delta HD = \sqrt{\Delta North^2 + \Delta East^2}$$

$$DLS = \frac{d}{\Delta MD} \cos^{-1}\left[\cos \Delta I - (\sin I_1 \cdot \sin I_2)(1-\cos \Delta A)\right]$$

Positive Displacement Mud Motor



1 : 2 Lobe Configuration for High Speed and Low Torque

5 : 6 Multi-lobe Configuration for Lower Speeds and Higher Torque

Figure 7-4

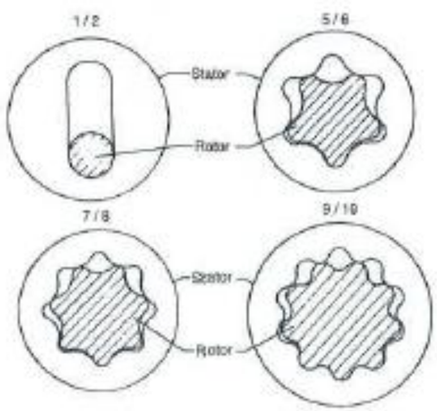
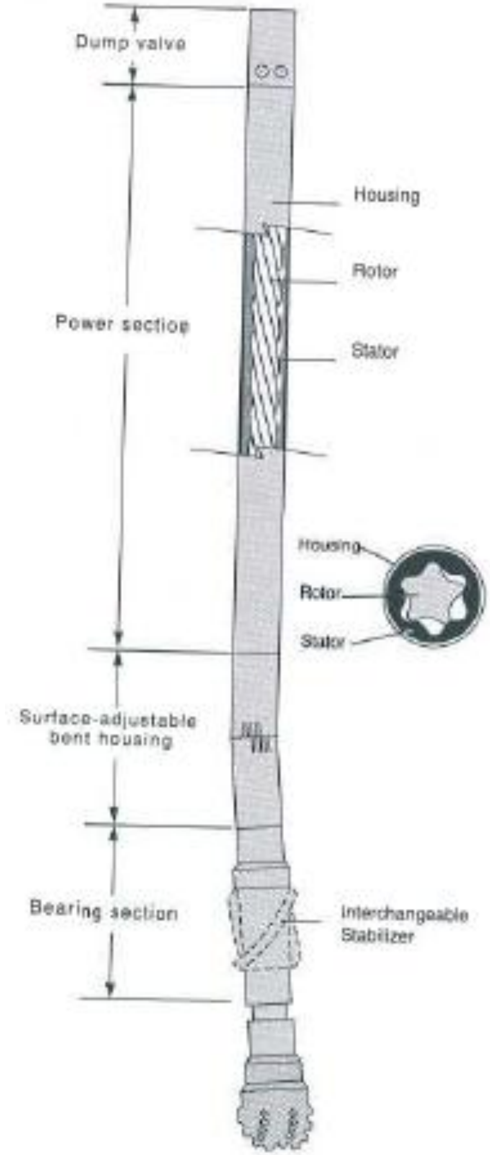
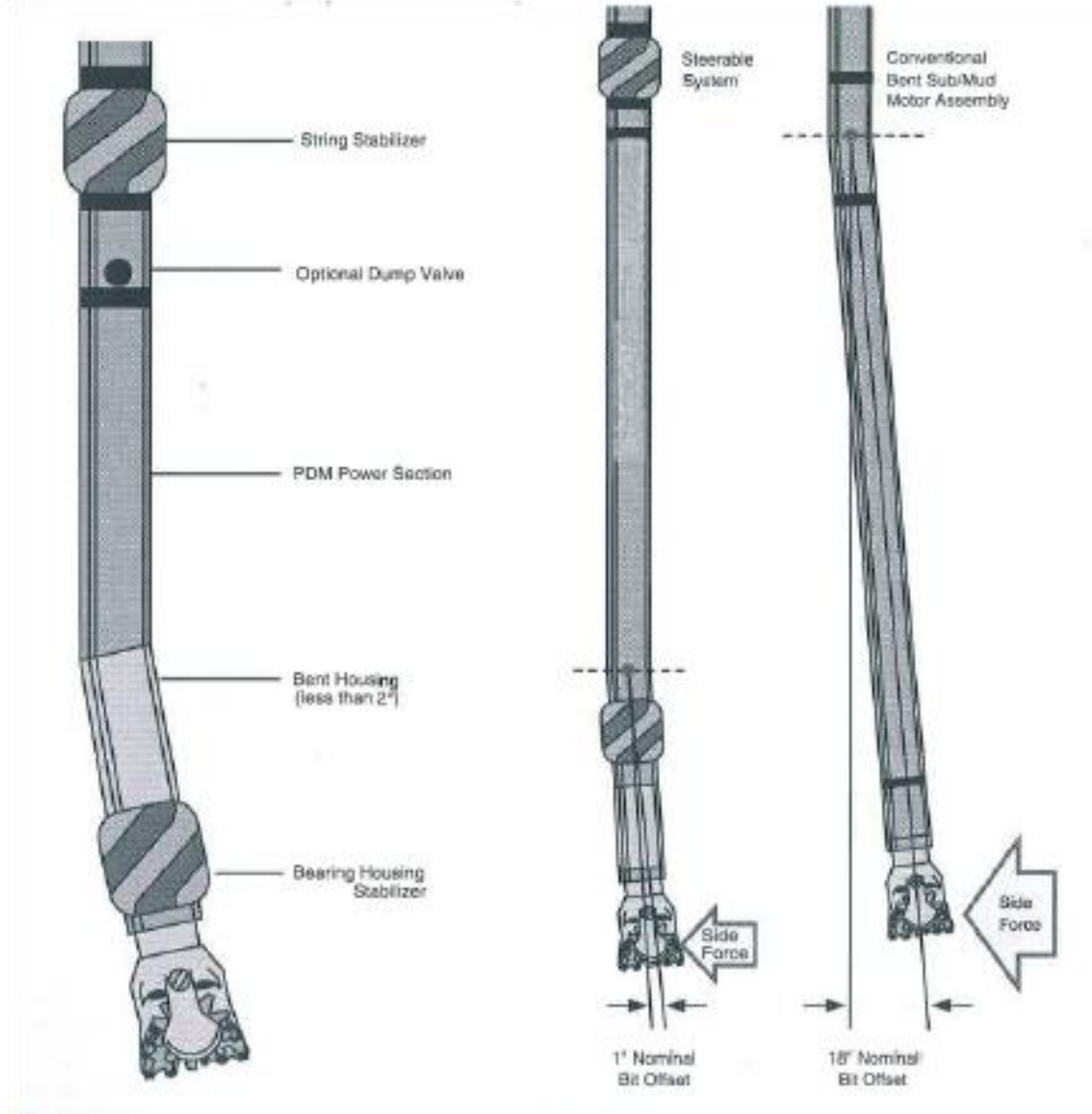


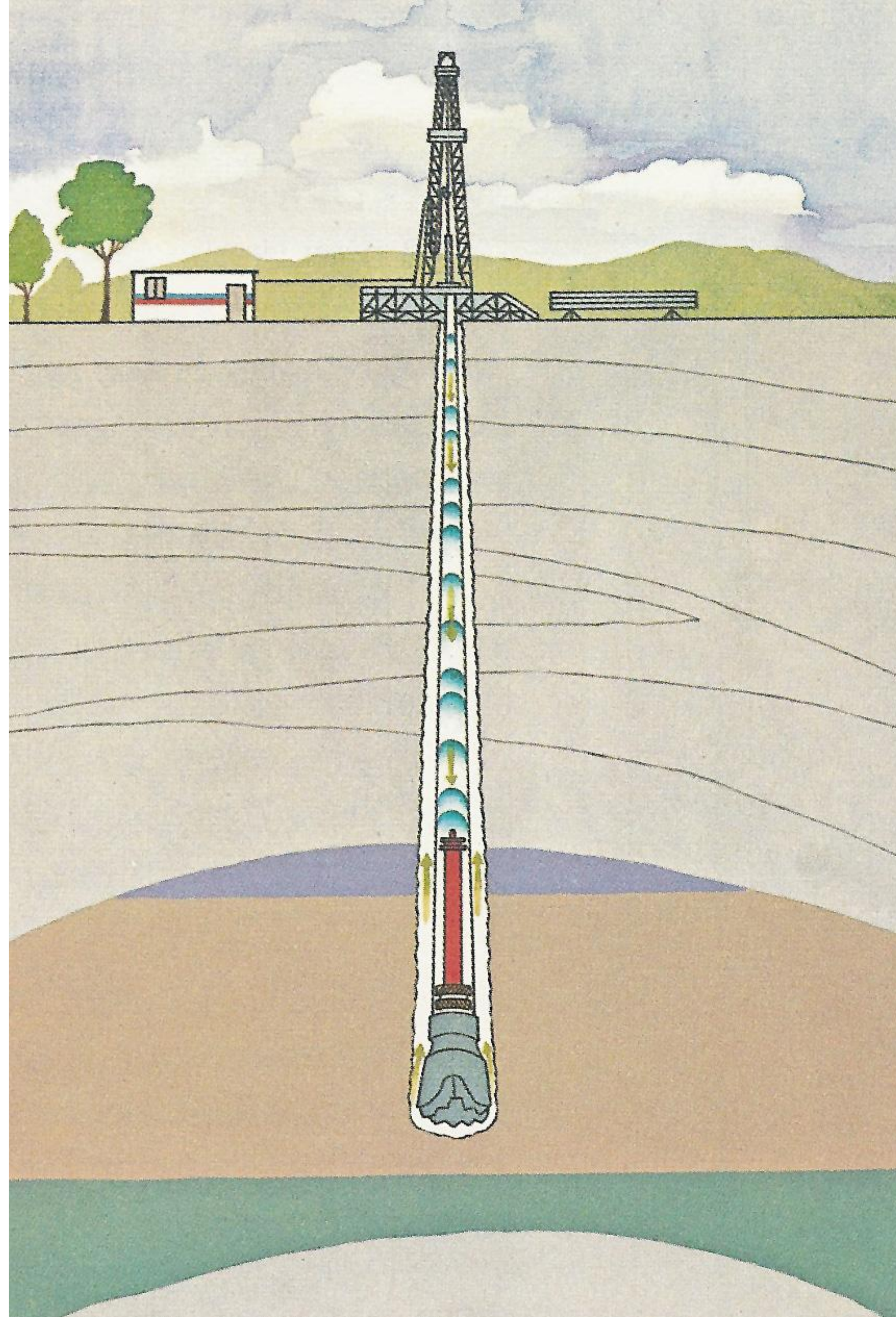
Figure 7-5 Illustrations of various motor profiles.



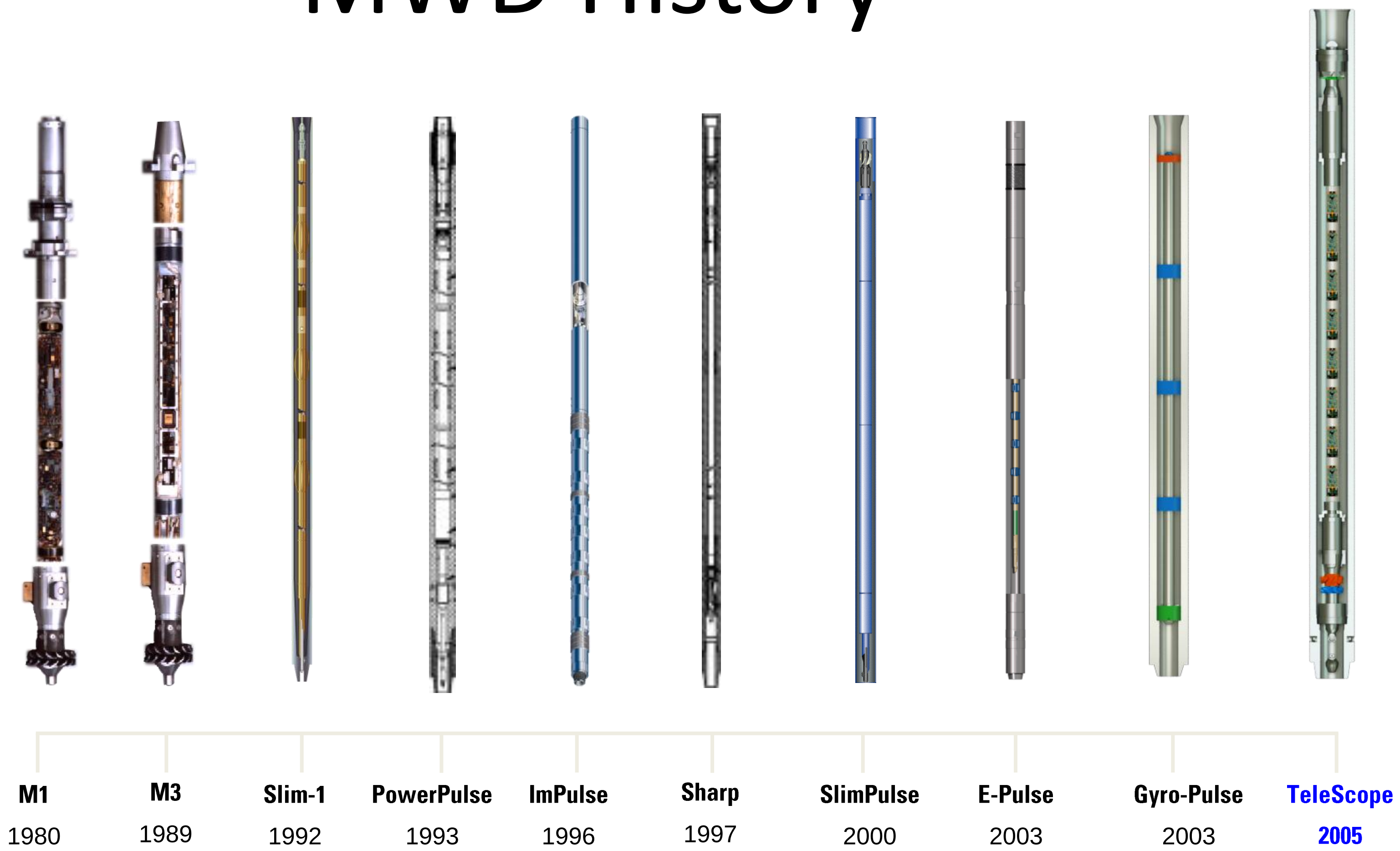
Steering With a Bent Motor



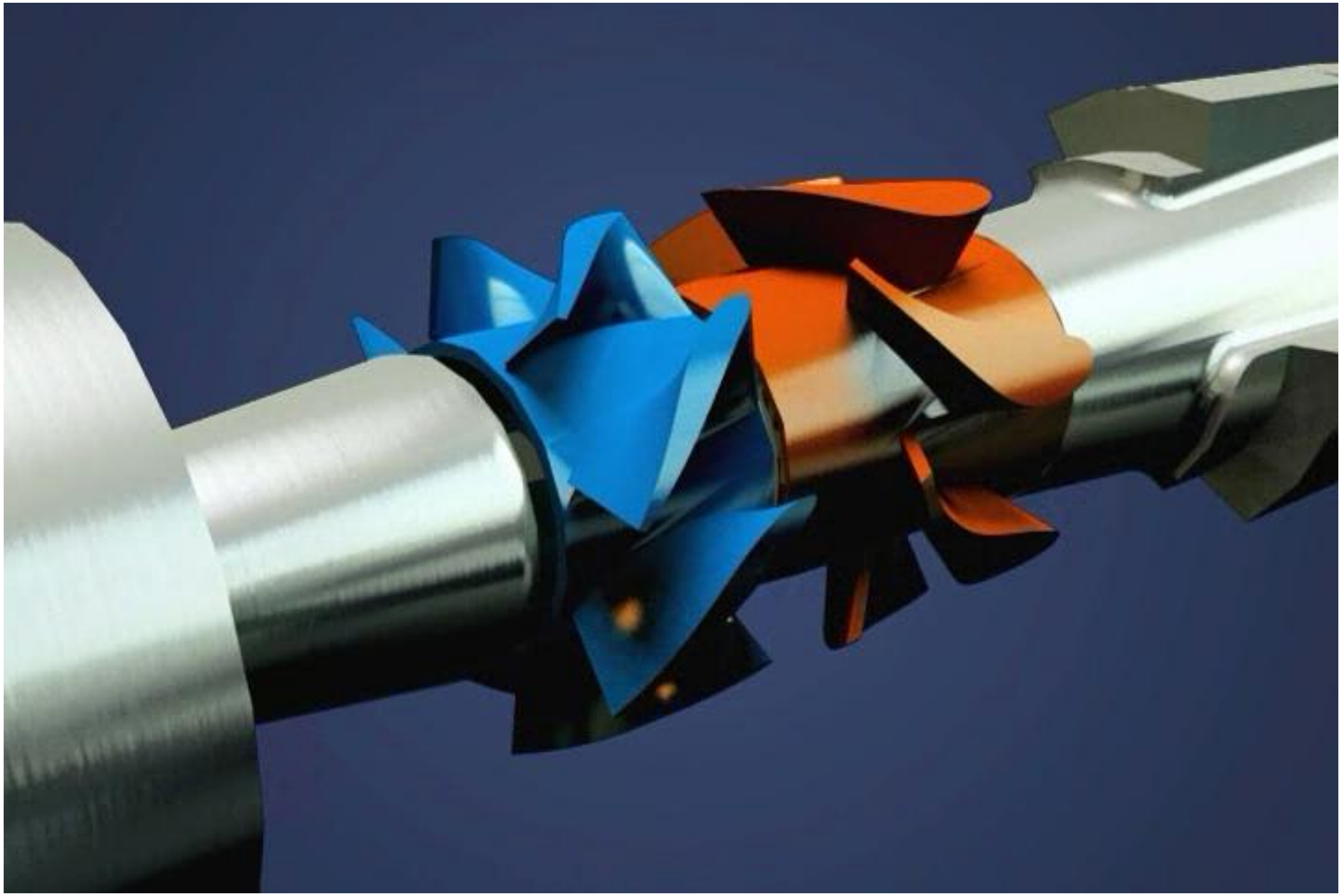
Measurement While Drilling (MWD)



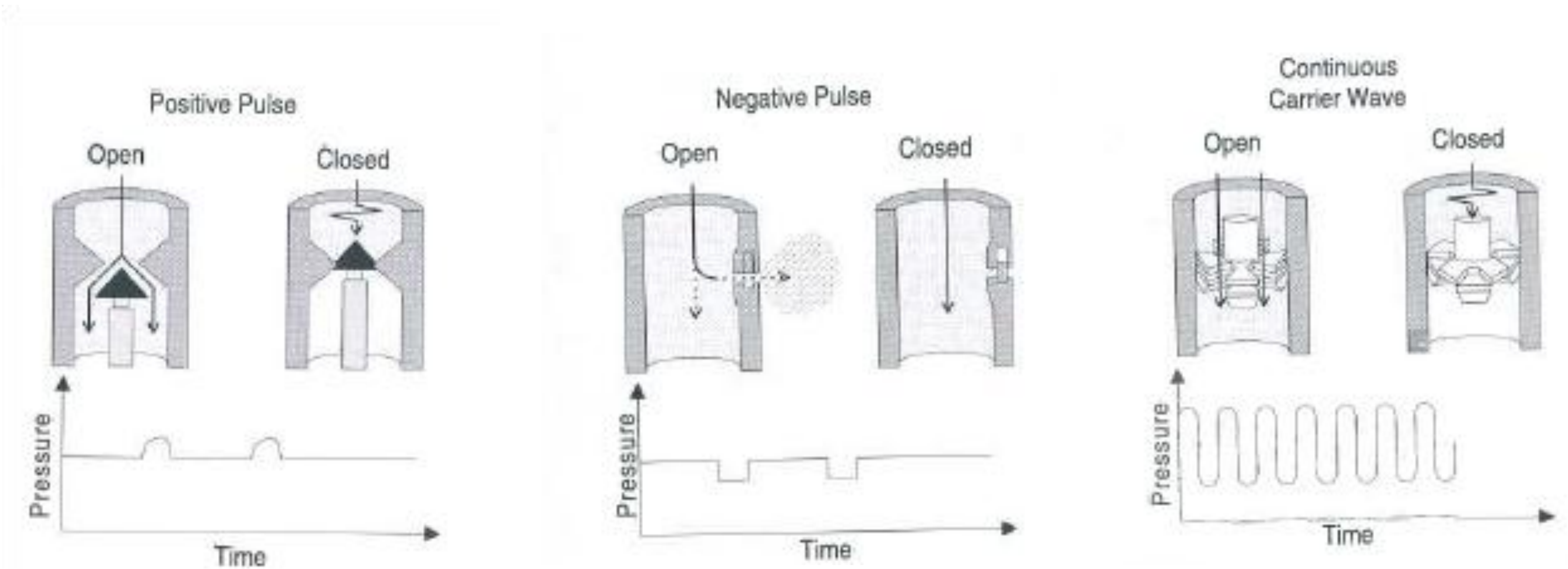
MWD History


M1
1980
M3
1989
Slim-1
1992
PowerPulse
1993
ImPulse
1996
Sharp
1997
SlimPulse
2000
E-Pulse
2003
Gyro-Pulse
2003
TeleScope
2005

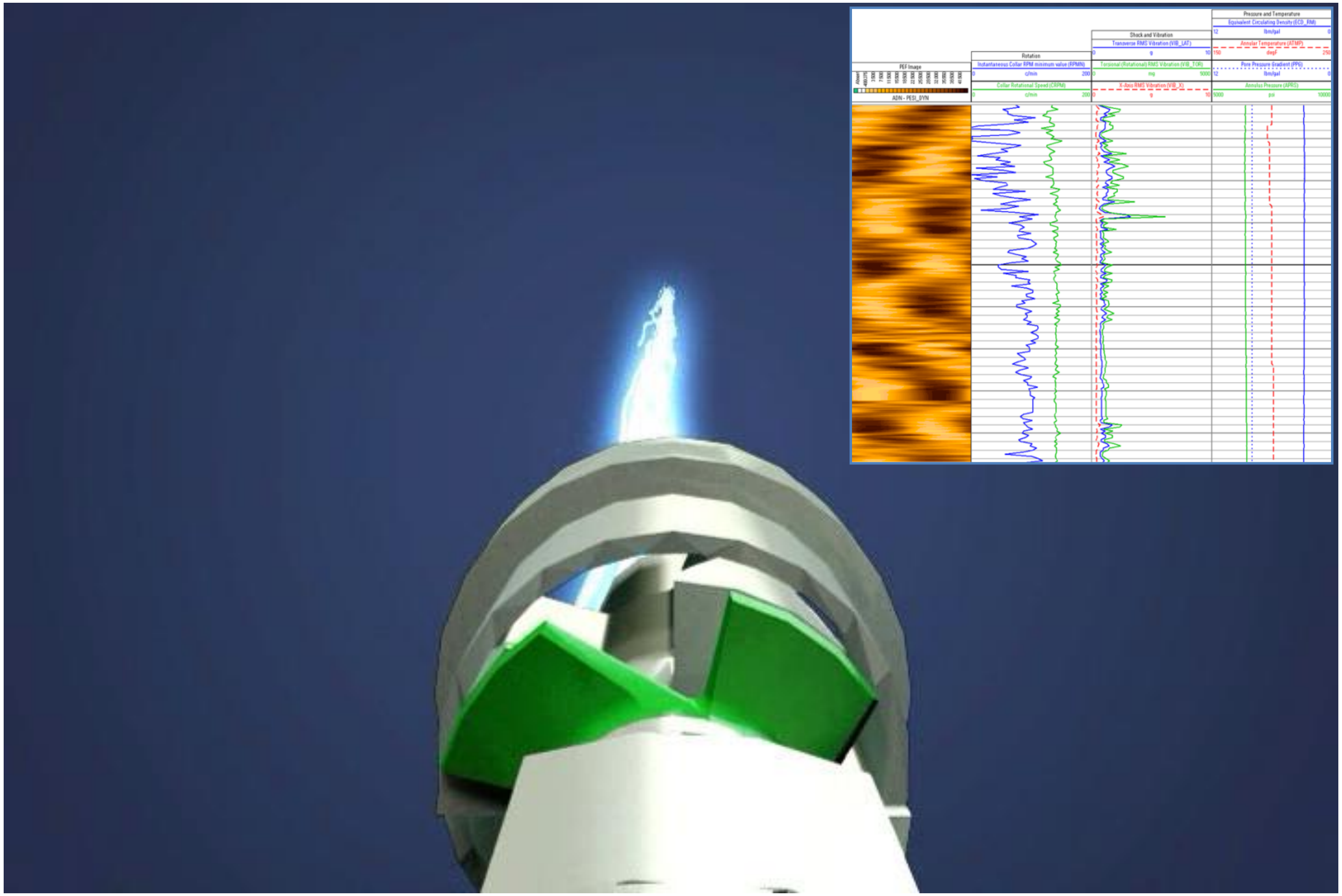
Power Turbo-Alternator



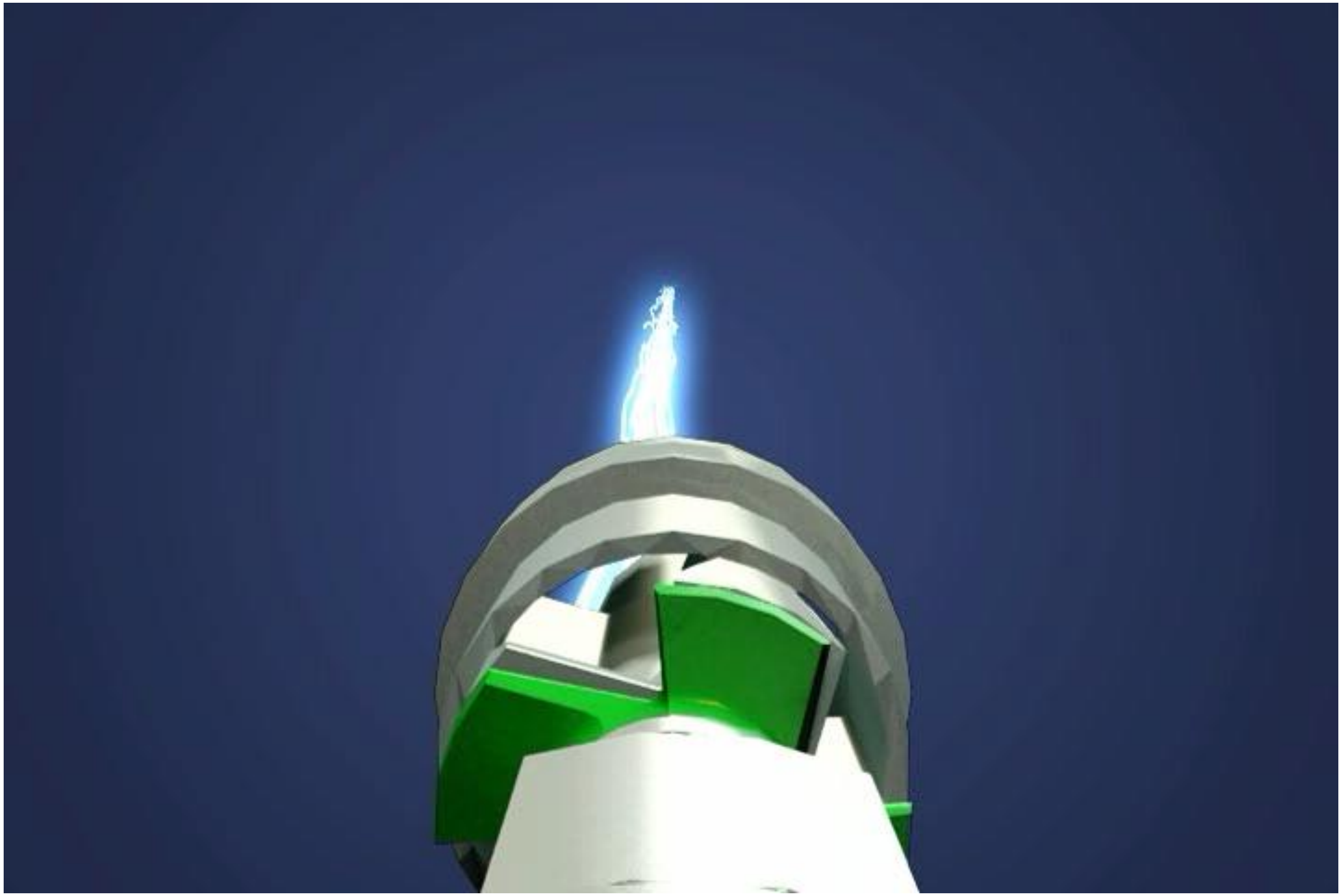
Mud-Pulse Hydraulic Telemetry!



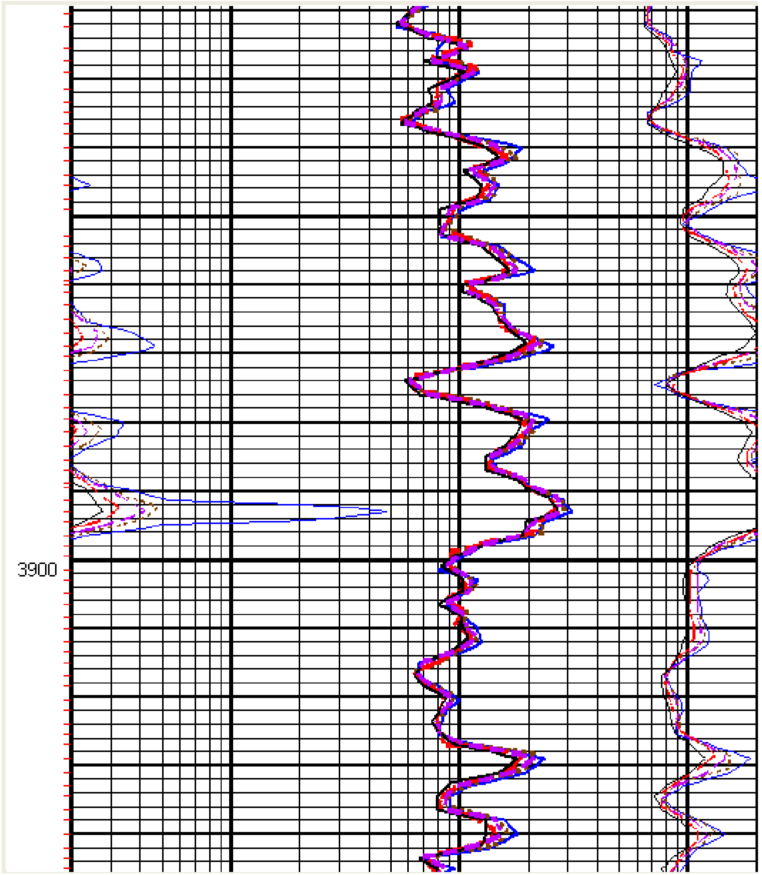
Mud-Pulse Siren



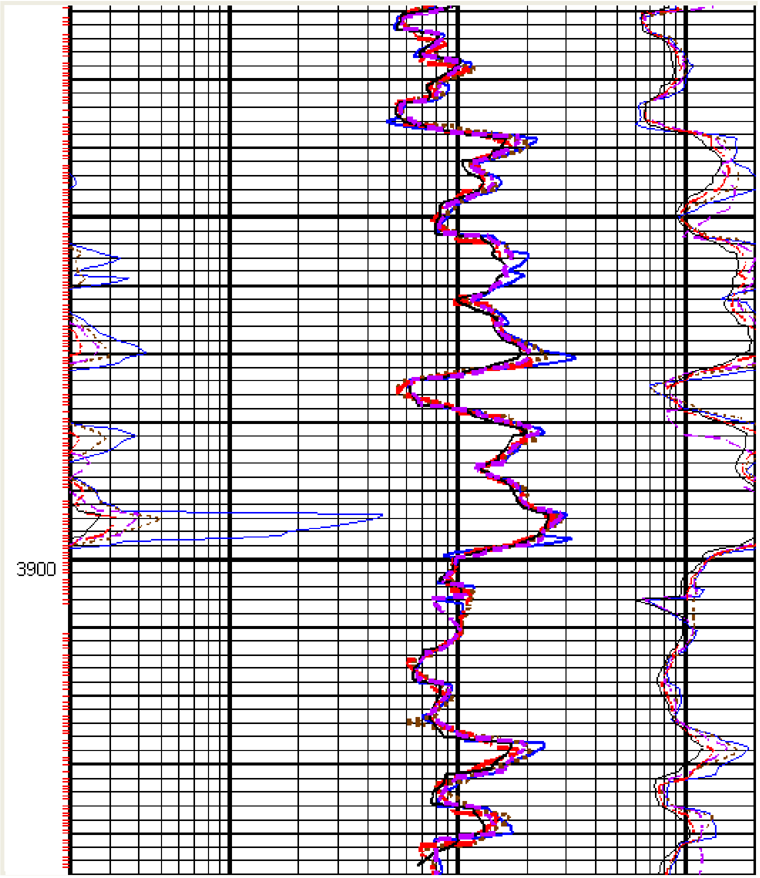
Mud-Pulse Siren



Mud-Pulse Transmission Example



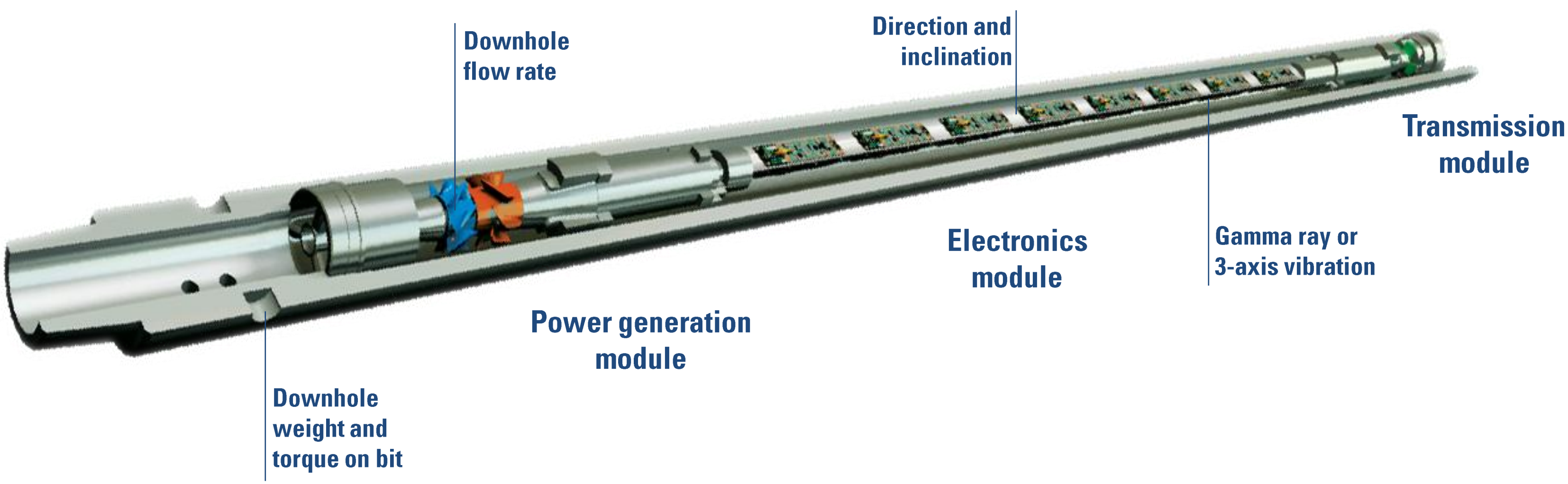
Real time Log @ 3bps



Real-time Log @ 12 bps

MWD Tool Specifications

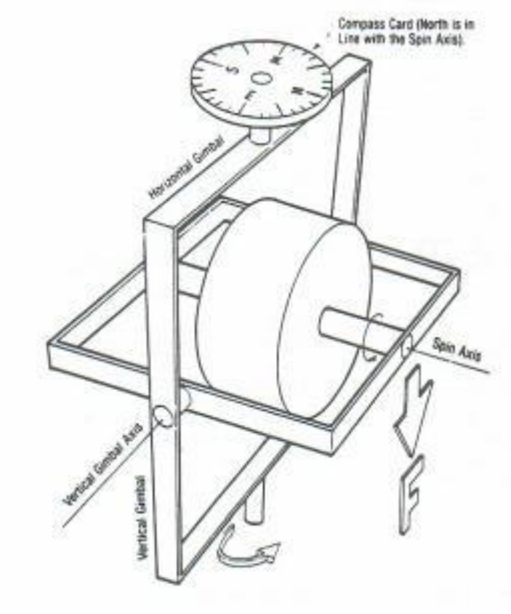
Available sizes	6¾”, 8¼”, 9”, 9½”
Power Supply	Turbine power
Operating frequencies	0.25 Hz – 24 Hz
GR real-time rate update period	3 seconds (min.)
GR recording rate	3 seconds (min.)
Continuous D&I/toolface RT update period	3 seconds (min.)
Continuous D&I recording rate	3 seconds (min.)
Shock sensor update period	3 seconds



Powerpulse Survey accuracy

Inclination accuracy (1σ)	(dega)	± 0.1
Azimuth accuracy (1σ) - below 5 dega inclination	(dega)	
- above 5 dega inclination	(dega)	± 1.0
Continuous survey		Standard
- update period	(s)	44
Range - minimum inclination	(dega)	20
- minimum angle from N-S	(dega)	30
Maximum vibration level	(Hz)	20
Continuous inclination - accuracy	(dega)	± 0.2
- resolution	(dega)	± 0.03
Continuous azimuth - accuracy	(dega)	± 2.0
- resolution	(dega)	± 0.1
Correction method for Drillstring Interference		DMAG

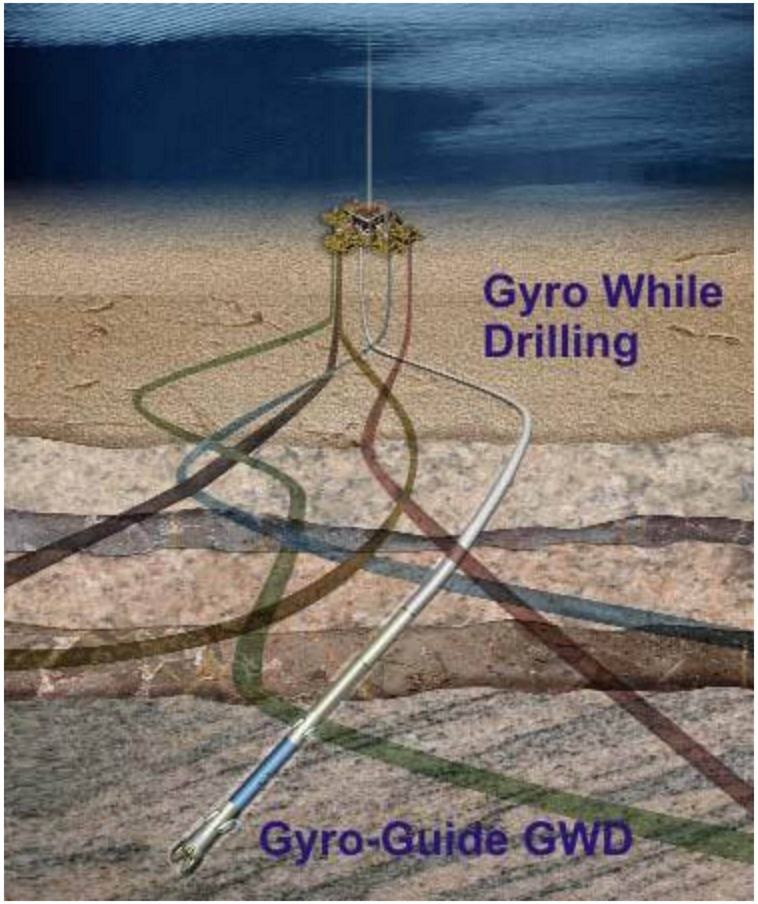
Gyroscopic Tools



- Gyro Theory
  - Balanced spinning mass
  - Free to rotate on one or more axis
  - Is resistant to external forces
- Two types of tools

1. Free Gyro
   – Tool aligned to a specific heading and variation from this heading, corrected for drift is measured
2. Earth Rate Gyro
   – Speed of earths rotation measured and processed to a specific azimuth

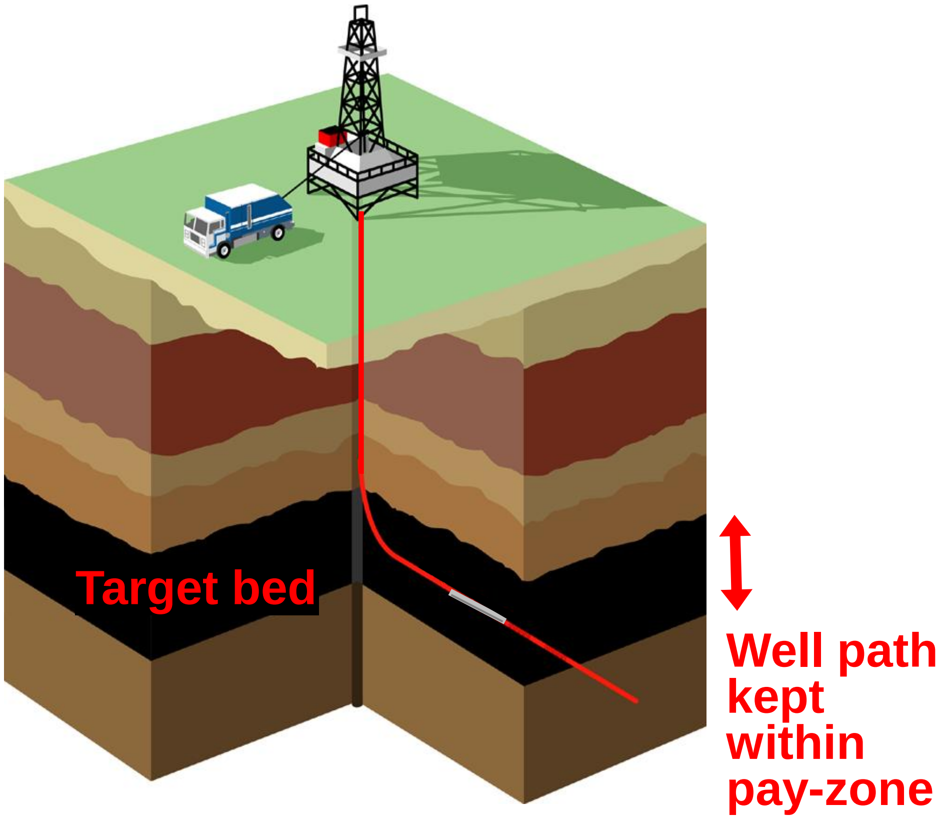
Gyro MWD Tools



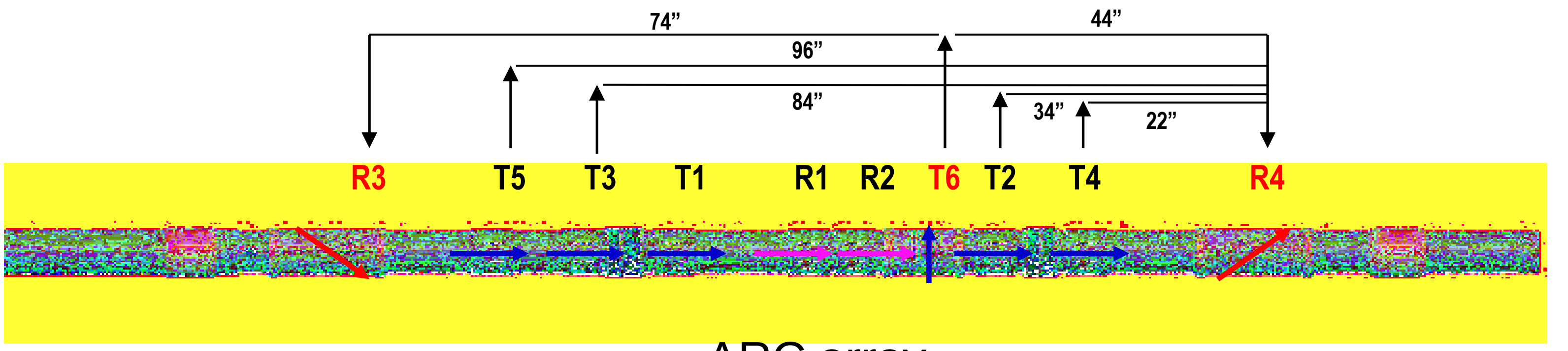
- **Enhanced Directional Control:**
- Since Gyro-Guide is not subject to magnetic interference, it can run below the MWD sensor section close to the bit—offering optimum directional control.

“GeoSteering” the Well Trajectory

- Pay zones are first identified in vertical exploration wells
- An induction-type tool is mounted on the drill-string behind the bit
- Near-horizontal well is drilled toward target bed
- Resistivity log is recorded while drilling and data is sent uphole in real time
- Actual log is compared to computed logs modeled for several well placement scenarios
- Well path adjusted accordingly to keep it within pay zone



"Periscope" – Directional Resistivity Tool



ARC array

- ARC resistivities
- Directional Antennas
  - T6 transverse transmitter
  - R3 and R4, 45° tilted receivers
- Deeper Measurements
  - spacing up to 96"
  - at three frequencies: 100 kHz, 400 kHz, 2 MHz

"Periscope" – Directional Resistivity Tool

Azimuthal and deep boundary mapping technology
- » Detects and maps a boundary up to 15 ft while drilling
- » Deep distance-to-boundary provides early warning
- » 360^{o} directional sensitivity provides best steering direction
- » Determines the boundary's orientation in real time

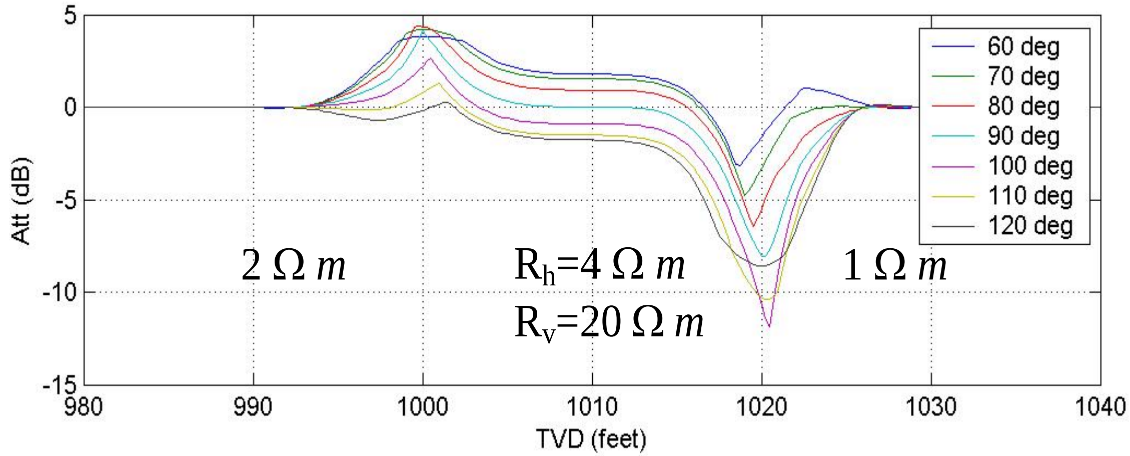
Simplified responses and interpretation:
- » Individual TR pair: provides a response sensitive to dip & anisotropy
- » Symmetrized TR pair: provides directional measurements insensitive to dip & anisotropy

Real-time interpretation & decisions

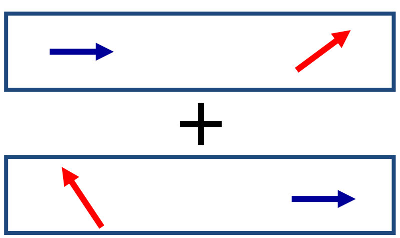
Symmetrization of Directional Measurements

Individual TR

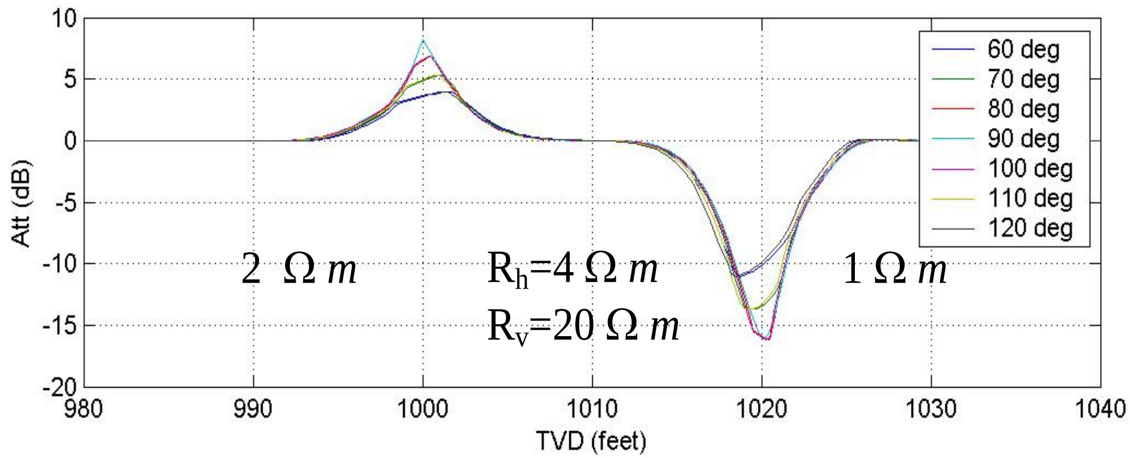
Sensitive to dip and anisotropy!



Symmetric TR Pair



Insensitive to dip and anisotropy!



Simplified response and interpretation!

Model-Based Parametric Inversion for Real-Time Interpretation

Model-based parametric inversion

Point-by-point 3 layer model inversion

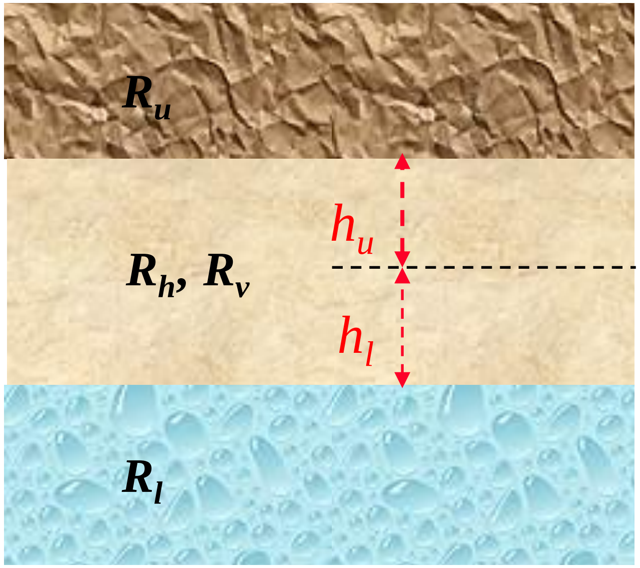
- Distances h_u, h_d
- Resistivities R_h, R_v, R_u and R_d

1-5 sec per point

Allow lateral variation of resistivity & dip

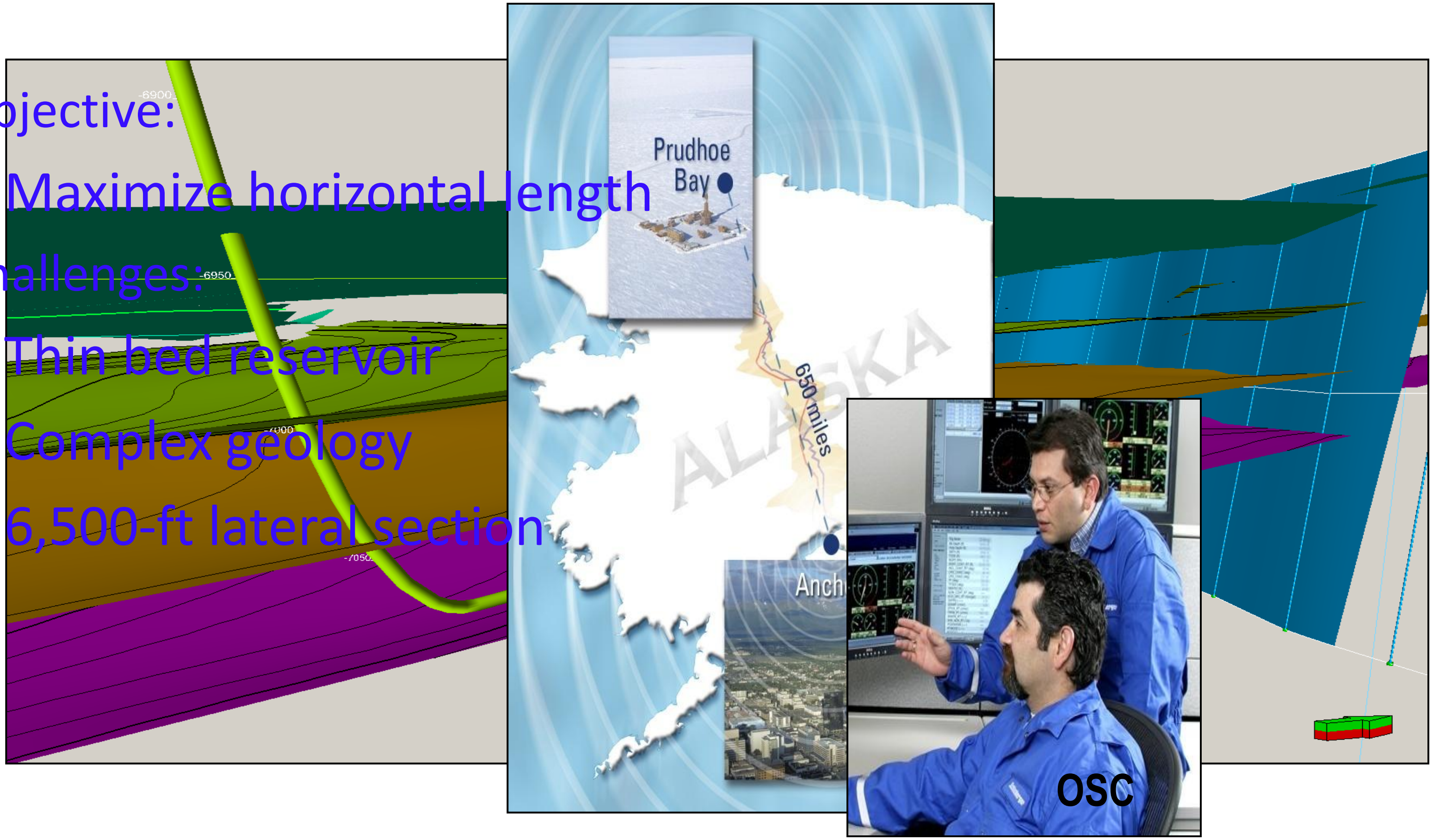
Automated selection of the simplest model that fits the data

Interactive model refinement if needed

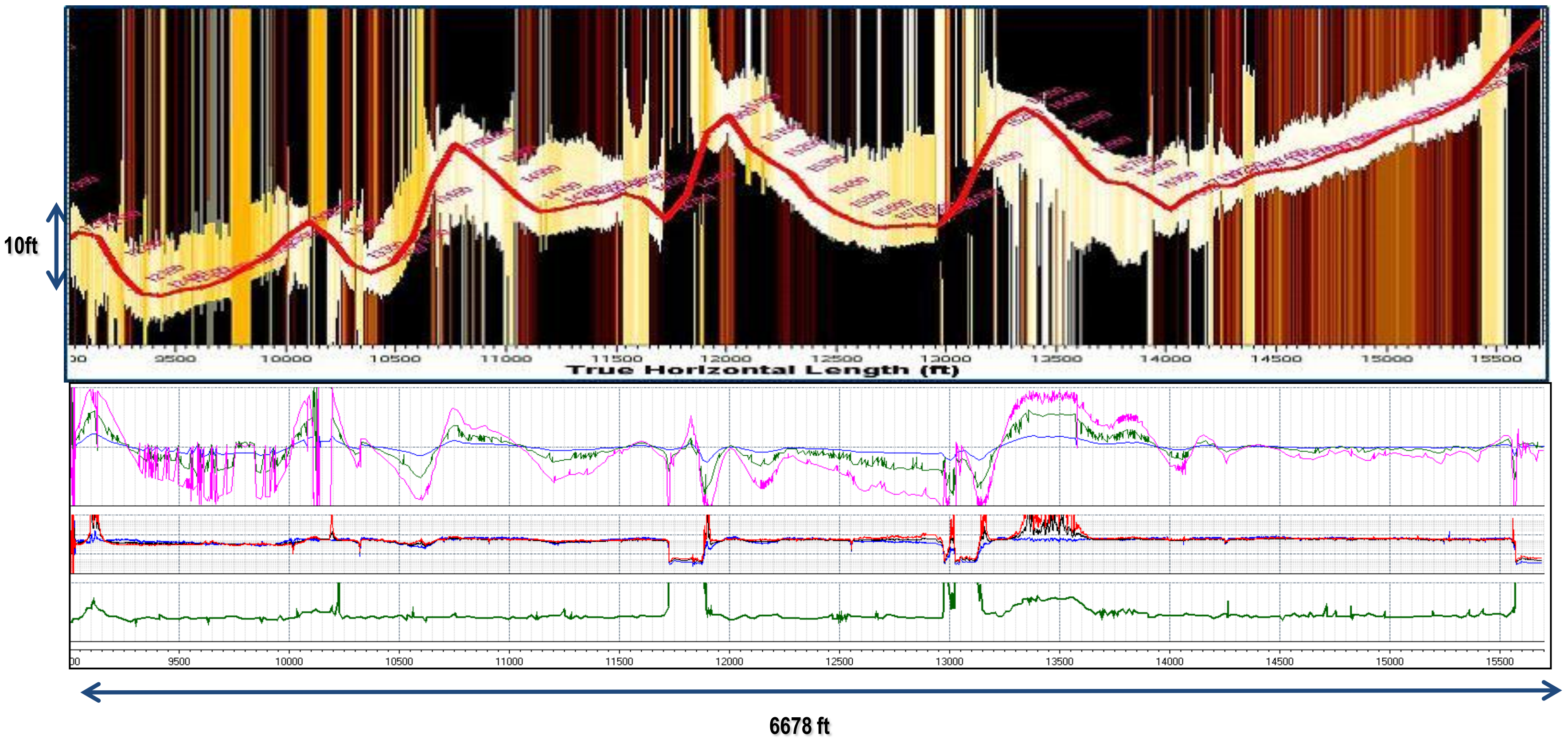


PeriScope – Case History from Alaska

- Objective:
  - Maximize horizontal length
- Challenges:
  - Thin bed reservoir
  - Complex geology
  - 6,500-ft lateral section



The Results



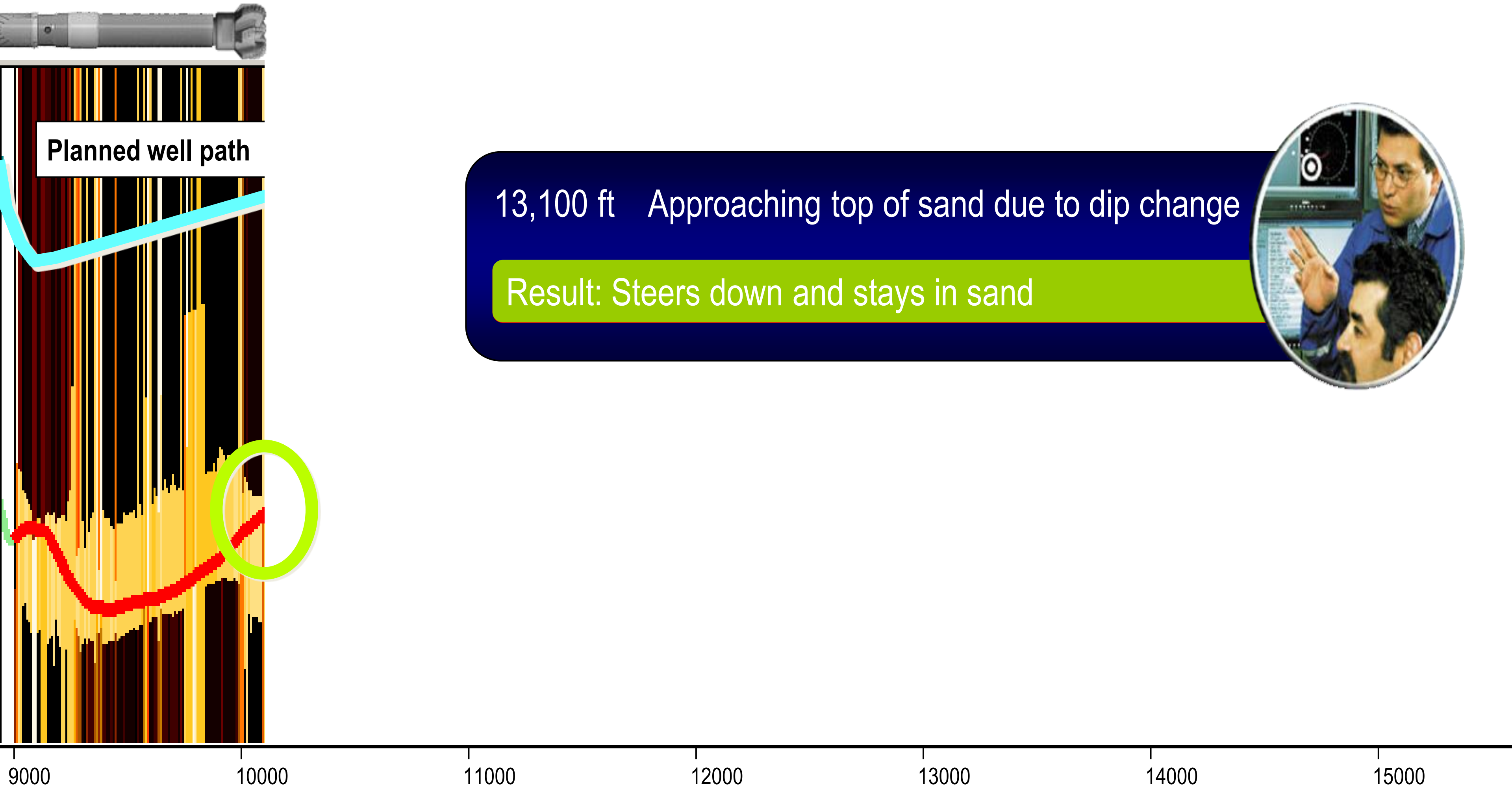
10ft
9500
10000
10500
11000
11500
12000
12500
13000
13500
14000
14500
15000
15500
True Horizontal Length (ft)
6678 ft

Steering Decisions

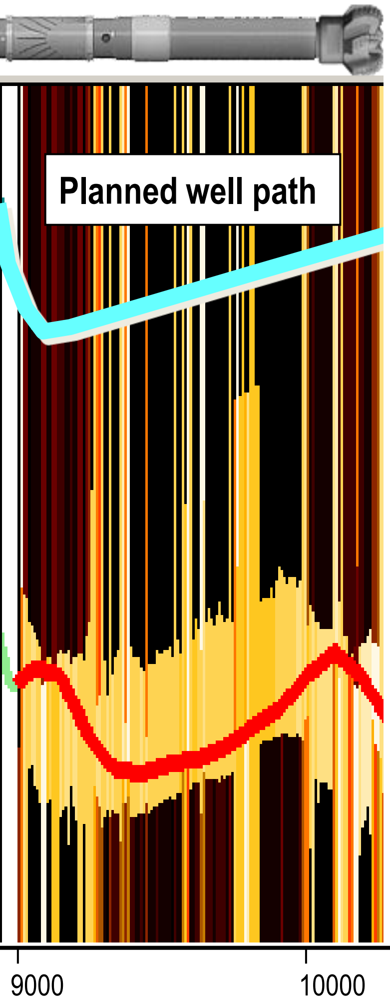
13,100 ft   Approaching top of sand due to dip change

9000 10000 11000 12000 13000 14000 15000

Steering Decisions



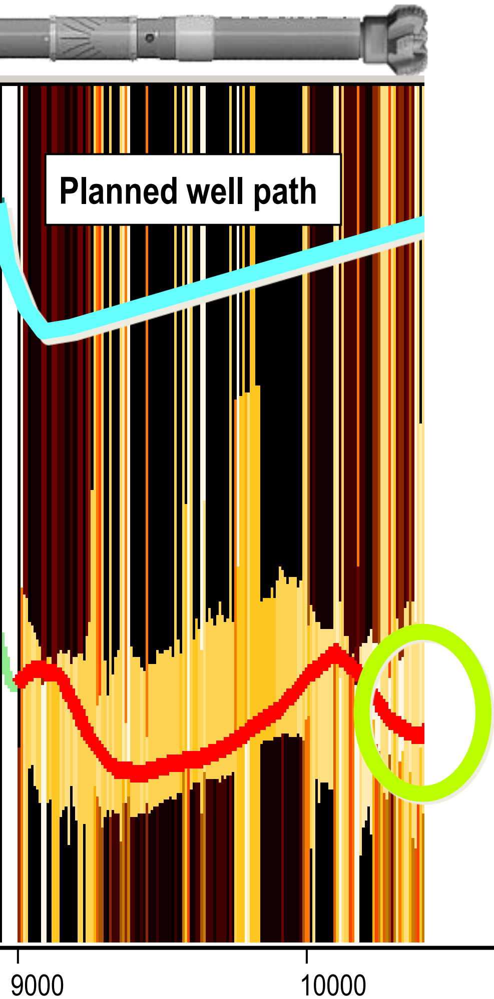
Steering Decisions



13,100 ft Approaching top of sand due to dip change

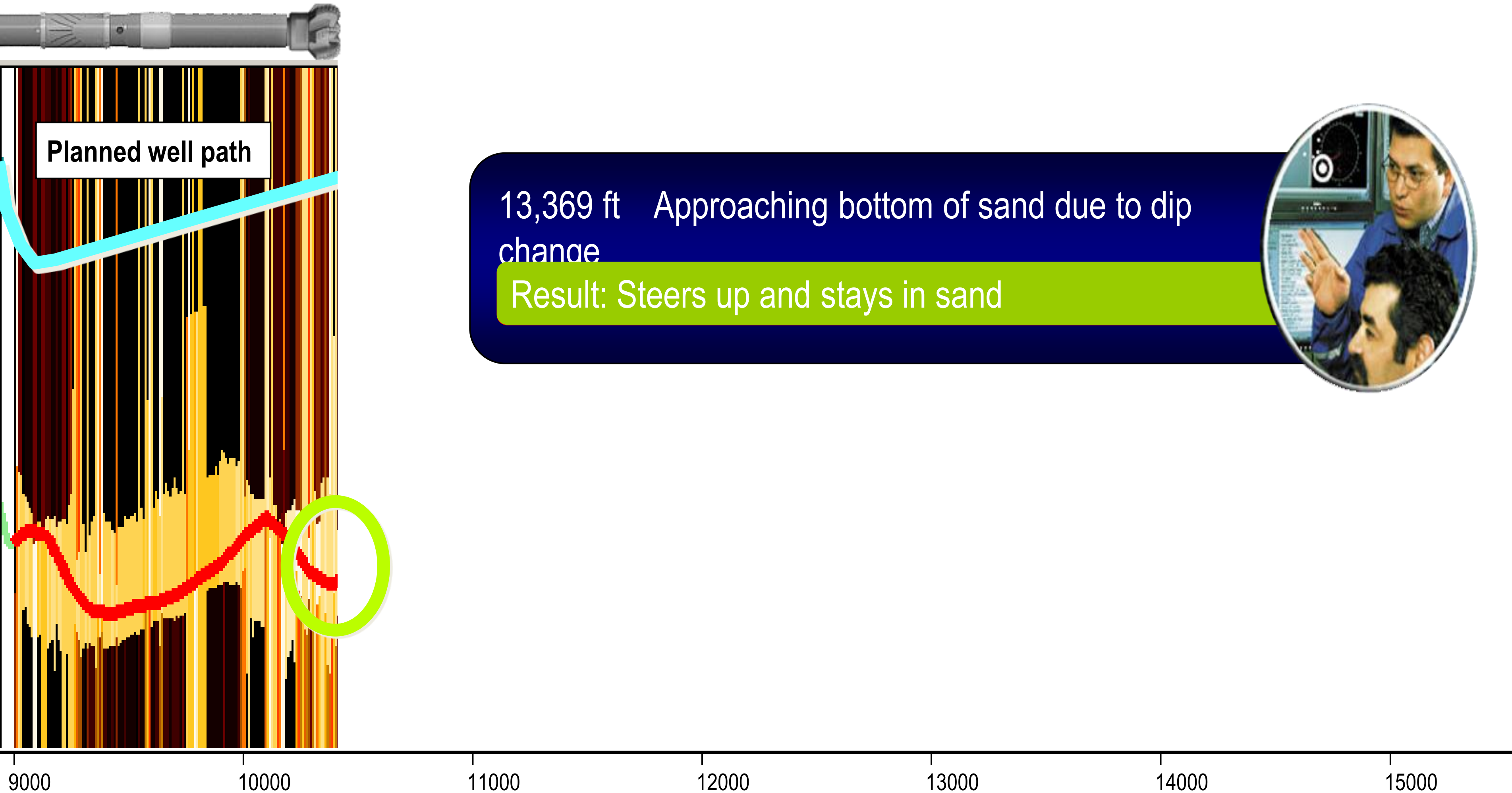
Result: Steers down and stays in sand

Steering Decisions



13,369 ft   Approaching bottom of sand due to dip change

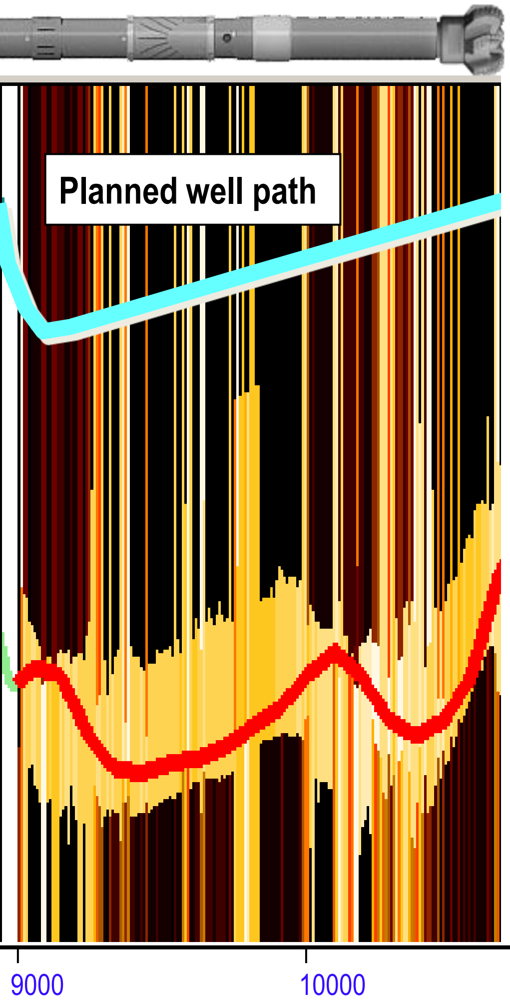
Steering Decisions



13,369 ft Approaching bottom of sand due to dip change

Result: Steers up and stays in sand

Steering Decisions

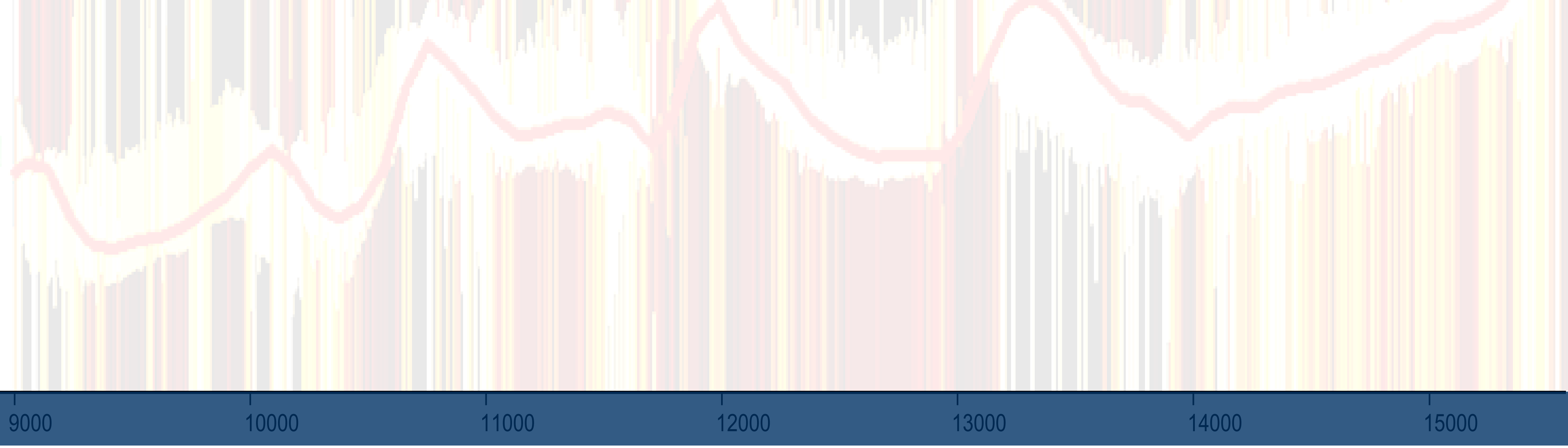


13,369 ft Approaching bottom of sand due to dip change

Result: Steers up and stays in sand

Client Benefits

- 93% in pay compared to typical 50-60%
- Production 60% higher than expected
- Client booked 5 million bbl of reserves
- 5 days of drilling time saved (by avoiding side-tracking)



Thank You!