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 1-6 Onshore drilling.

Figure 1-7 Offshore multiwell 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)
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
Drill dozens of wells off a single platform, whilst avoiding collisions with previous (producing) wells….
Analysis Methods

- Subject (proposed) Well
- Object (offset) Well
- Closest Approach
- 3D least distance
- Normal Plane
- Horizontal Plane
Basic Geometrical Well Plan

**CALCULATIONS**

<table>
<thead>
<tr>
<th>VERTICAL DEPTH</th>
<th>HORIZONTAL DISPLACEMENT</th>
<th>MEASURED DEPTH</th>
</tr>
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<tbody>
<tr>
<td>KOP</td>
<td>V₁</td>
<td>D₁</td>
</tr>
<tr>
<td>END OF BUILD</td>
<td>V₂</td>
<td>D₂</td>
</tr>
<tr>
<td>START DROP</td>
<td>V₃</td>
<td>D₃</td>
</tr>
<tr>
<td>END DROP</td>
<td>V₄</td>
<td>D₄</td>
</tr>
<tr>
<td>TARGET</td>
<td>V₅</td>
<td>D₅</td>
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</tbody>
</table>

**MAX. INCLINATION**

Ω

**BUILD UP RATE BUR**

BUR = (1100/100 FT) =

**DROP OFF RATE DOR**

DOR = (780/100 FT) =

**RADIUS OF CURVATURE, R₁**

R₁ = (BUR x f) =

R₁ = (DOR x f) =

**Line X**

X = D₅ - (R₁ + R₉)

**Angle B**

B = tan(X)

**Line OF**

OF = V₁/ Cos B

**Line OG**

OG = √(OF² + (R₁ + R₉)²) =

**Angle FOG**

FOG = sin⁻¹ [(R₁ + R₉)/ OF]

**Angle Ω**

Ω = Angle FOG + β

**End of Build**

Measured depth = V₁ + Ω

Vertical depth, V₁ = V₁ + R₁ Sin Ω

Displacement, D₁ = R₁ (1 - Cos Ω)

**Start of Drop**

Measured depth = V₁ + Ω + OG

Vertical depth, V₁ = V₁ + OG Cos Ω

Displacement, D₂ = D₁ + OG Sin Ω

**End of Drop**

Measured depth = V₁ + Ω + OG + Ω

Vertical depth = V₅

Displacement, D₅

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*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

- 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
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:

\[
RF = \frac{360}{DL \cdot \pi} \tan \left( \frac{DL}{2} \right) \quad \text{or} \quad RF = \frac{360}{DL \cdot \pi} \cdot \frac{1 - \cos DL}{\sin DL}
\]

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

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

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

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

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

Figure 7-4: 1:2 Lobe Configuration for High Speed and Low Torque
Figure 7-5: Illustrations of various motor profiles.
Steering With a Bent Motor
Measurement While Drilling (MWD)
MWD History

<table>
<thead>
<tr>
<th>Model</th>
<th>Year</th>
</tr>
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<tbody>
<tr>
<td>M1</td>
<td>1980</td>
</tr>
<tr>
<td>M3</td>
<td>1989</td>
</tr>
<tr>
<td>Slim-1</td>
<td>1992</td>
</tr>
<tr>
<td>PowerPulse</td>
<td>1993</td>
</tr>
<tr>
<td>ImPulse</td>
<td>1996</td>
</tr>
<tr>
<td>Sharp</td>
<td>1997</td>
</tr>
<tr>
<td>SlimPulse</td>
<td>2000</td>
</tr>
<tr>
<td>E-Pulse</td>
<td>2003</td>
</tr>
<tr>
<td>Gyro-Pulse</td>
<td>2003</td>
</tr>
<tr>
<td>TeleScope</td>
<td>2005</td>
</tr>
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</table>
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

![MWD tool diagram]

**Diagram details:**
- Downhole flow rate
- Direction and inclination
- Transmission module
- Electronics module
- Power generation module
- Downhole weight and torque on bit
- Gamma ray or 3-axis vibration
# Powerpulse Survey accuracy

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Accuracy</th>
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<tbody>
<tr>
<td>Inclination accuracy (1σ)</td>
<td>dega</td>
<td>± 0.1</td>
</tr>
<tr>
<td>Azimuth accuracy (1σ) - below 5 dega inclination</td>
<td>dega</td>
<td>± 1.0</td>
</tr>
<tr>
<td>- above 5 dega inclination</td>
<td>dega</td>
<td>± 1.0</td>
</tr>
<tr>
<td>Continuous survey</td>
<td></td>
<td>Standard</td>
</tr>
<tr>
<td>- update period</td>
<td>s</td>
<td>44</td>
</tr>
<tr>
<td>Range - minimum inclination</td>
<td>dega</td>
<td>20</td>
</tr>
<tr>
<td>- minimum angle from N-S</td>
<td>dega</td>
<td>30</td>
</tr>
<tr>
<td>Maximum vibration level</td>
<td>Hz</td>
<td>20</td>
</tr>
<tr>
<td>Continuous inclination - accuracy</td>
<td>dega</td>
<td>± 0.2</td>
</tr>
<tr>
<td>- resolution</td>
<td>dega</td>
<td>± 0.03</td>
</tr>
<tr>
<td>Continuous azimuth - accuracy</td>
<td>dega</td>
<td>± 2.0</td>
</tr>
<tr>
<td>- resolution</td>
<td>dega</td>
<td>± 0.1</td>
</tr>
<tr>
<td>Correction method for Drillstring Interference</td>
<td></td>
<td>DMAG</td>
</tr>
</tbody>
</table>
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 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° 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
Steering Decisions

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

Planned well path

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

Result: Steers down and stays in sand
Steering Decisions

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

Result: Steers down and stays in sand
Steering Decisions

Planned well path

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!