Drilling Services Technology

Introduction to Logging-While-Drilling
MWD and LWD

- LWD provides formation evaluation measurements
- MWD provides drilling mechanics and survey measurements
  - It also transmits data up hole by mud pulse telemetry
BHA Configured with LWD

HEL (Dir/GR/BAP/ESM)

TNP

AZD

MFR

RSS
HEL™ System Components

Pressure Modulated Telemetry (PMT™) assembly

ESM Environment Severity Measurement sensor or TVM Total Vibration Monitor

Dual Battery Module (DBM™) assembly

High Temperature Azimuthal Gamma Ray (HAGR™) tool

Bore/Annular Pressure (BAP™) tool

Integrated Directional Sonde (IDS™) tool
EMpulse™ MWD system
Wired Pipe: A New Era in Telemetry

- Transmission: High-Speed, Bi-Directional Network at 57,000 bps (mud pulse currently 3-50 bps). Inductive coupling enables communication in all drilling fluids.

- Bottom Open Network allows acquisition of MWD/LWD/RSS tools from bottom of string. Instantaneous actuation of downhole tools.

- Innovation to the Industry: Capable of measurements along string via measurement nodes
LWD Sensors

- Gamma Ray
  - HAGR – High-Temperature Azimuthal Gamma Ray
  - SAGR - Spectral Azimuthal Gamma Ray

- Resistivity - MFR – Multi-Frequency Resistivity

- AZD - Azimuthal Density

- TNP – Thermal Neutron Porosity

- ShockWave Sonic

- PressureWave Formation Tester
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Gamma Ray Introduction

The Gamma Ray Curve:

- Measures the naturally occurring radiation from the rocks surrounding the borehole.
- It’s a passive recording.
- Shales usually exhibit higher levels of radiation than non-shale formations.
High-Temperature Azimuthal Gamma Ray (HAGR)

- **4-3/4” Insert**
  - 10 tubes (5 x 2)

- **6-3/4” Insert**
  - 16 tubes (8 x 2)

- **8-1/4 & 9-1/2” Insert**
  - 18 tubes (6 x 3)
HAGR Placement Options

- Middle of the HEL Collar
- Bottom of the MFR Collar
- Top of the RSS Tool
- MFR
- TNP
- AZD
- HEL (Dr/GR/BAP/ESM)
As the tool rotates, X- and Y-axis magnetometers track the orientation of each detector tube.

As each gamma ray count is detected, it is placed in one of 8 azimuthal bins, based on the detector position at the time of detection.

Total, Up/Down, Quadrant, and Octant GR count rates and API values are computed at the end of each sample period.
The 8 azimuthally oriented GR curves... are interpolated vertically and circumferentially to produce a 360° borehole image. Dips are computed from planar features picked on the image log.
Bed is dipping 44 deg. to the southeast.

“Body” of the tadpole gives dip angle (from horizontal) on the 0-90 horizontal grid scale.

“This” of the tadpole gives dip direction on a 0-360 azimuth scale.
HAGR Image Across Major Unconformity

- **ROP**: 0 fph
- **HAGR_UP**: 0 gap (20) 150 gap (150)
- **HAGR_DN**: 0 gap (20) 150 gap (150)
- **Hole Drift**: 65 deg (115)

### Static GR Image (15-115 gap)

1:400

- **Total Gamma Ray**
- **Fault**
- **OtherSurface**
- **Bedding**
- **BedBoundary**

### Dips

- **Fault**
- **OtherSurface**
- **Bedding**
- **BedBoundary**

### Dynamic GR Image

- **Fault**
- **OtherSurface**
- **Bedding**
- **BedBoundary**

### Azimuth Freq. & Dip Histogram
HAGR Summary

- Environment: 180°C (356°F), 30,000 psi
- Tool Sizes: 4-3/4”, 6-3/4”, 8-1/4”, 9-1/2”
  - Sensor configuration optimized for each tool size
- Output:
  - Total GR
  - Up / Down GR
  - Up / Down / Left / Right quadrant curves
  - 8-Bin Borehole Image (Real-Time & Recorded)
- Applications:
  - Correlation, Vsh
  - Geosteering, Basic structural information
- Can be placed in HEL, MFR, or RSS collars to get close to bit.
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Spectral Gamma Ray

- Spectral Gamma Ray devices are also “passive” detectors of radioactive gamma ray decay occurring within formations.
- Unlike natural gamma devices, the spectral device uses a detector which can distinguish the origin of each gamma ray it detects.
- This can be done because potassium, thorium, and uranium each have unique decay spectrums.

![Gamma Ray Emission Spectra](image)
Spectral Azimuthal Gamma Ray (SAGR) Tool

- Hardware
  - 3 large scintillation detectors
    - 1.5” x 8” gain-stabilized NaI detector crystals
    - Mounted in pocket on the outside of the drill collar, 120 deg. apart
  - X and Y magnetometers for azimuthal binning
  - 256 MB memory

- Measurements
  - Total gamma ray
  - Spectral gamma ray
    - Potassium Concentration (%)
    - Uranium Concentration (ppm)
    - Thorium Concentration (ppm)
  - Azimuthally binned total GR
    - 4 quadrants (Up, Down, Left, Right)
    - 16 bins (Real-Time & Recorded)
Same amount of Potassium

Difference is U, Th

Same amount of Potassium
SAGR in Barnett Shale Horizontal Well
SAGR Applications

The SAGR tool addresses three distinct applications:

Spectral Gamma Ray Measurement

- Clay typing
- Organic shale evaluation
  - Uranium associated w/ organic matter
  - Clay-content vs. brittleness relationships

Azimuthal Gamma Ray / Borehole Imaging

- Geosteering and basic structural information

Fast Logging / High Resolution Gamma Ray Logging

- Count rate ~ 50 times higher than standard LWD GR
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Specific Resistance, or *Resistivity* is computed as follows:

\[
\text{Resistivity} = \frac{V}{I} \times \frac{A}{L}
\]


Units of Resistivity = \(\Omega \times m^2 / m\), or \(\Omega \times m\)
LWD propagation resistivity tools emit radio-frequency electromagnetic waves from a transmitter, and measure the velocity (phase shift) and attenuation (amplitude ratio) between two receiver antennas.
The velocity of radio waves slows as they pass through conductive formations.
The phase shift measurement tells us what fraction of one wave length is represented by the inter-receiver spacing.

\[
\frac{\text{phase shift}}{360} = \frac{\text{receiver spacing}}{\text{wave length}}
\]

Low Resistivity = Slow Velocity = Short Wave Length = Large Phase Shift

Phase Shift = 130 deg.
The phase shift measurement tells us what fraction of one wave length is represented by the inter-receiver spacing.

\[
\frac{\text{phase shift}}{360} = \frac{\text{receiver spacing}}{\text{wave length}}
\]

Phase Shift = 25 deg.

High Resistivity = Fast Velocity = Long Wave Length = Small Phase Shift
The amplitude ratio measurement tells us how much the amplitude of the propagating wave is attenuated between the near and far receivers.

Low Resistivity = High Attenuation = Large Amplitude Ratio
The amplitude ratio measurement tells us how much the amplitude of the propagating wave is attenuated between the near and far receivers.

High Resistivity = Low Attenuation = Small Amplitude Ratio

Attenuation = 0.25dB
Phase Shift vs. Attenuation

- Shallower reading
- Better vertical resolution
- More accurate at high resistivity

- Deeper reading
- Poorer vertical resolution
- Less accurate at high resistivity
Multi-Frequency Resistivity (MFR)

- Fully Compensated Antenna Design
- 20", 30", 46" Antenna Spacings
- Dual Frequency – 2 MHz and 400 kHz
- Phase and Attenuation – 12 Independent Resistivity Measurements
- 180°C (356°F) Temperature Rating
- 30,000 PSI Pressure Rating
- Extensive Modelling and Interpretation Software
Depth of Investigation

Depth of Investigation - Phase & Attenuation

![Graph showing Depth of Investigation vs. Resistivity (ohmm)]

- DOI (Inches - 50% RPGF)
- Resistivity (ohmm)
- Curves for different depths and frequencies:
  - 20" 2 MHz
  - 30" 2 MHz
  - 46" 2 MHz
  - 20" 0.4 MHz
  - 30" 0.4 MHz
  - 46" 0.4 MHz
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Density Measurement

**Cs\textsubscript{137} Gamma ray Source**

**Short Spacing Detector**

**Long Spacing Detector**

Gamma rays emitted
Density Sensor Theory

• The LWD density sensor detectors measure gamma counts through low density windows in a blade on the drill collar.

• The “detector blade” is forced against the borehole wall by the rotating action of the drillstring.

• The blade will generally not remain in contact 100% of the time creating a condition called “standoff”.
Density Sensor Theory

- If the near and far density values fall on the “spine” (45° line) it indicates that there is no standoff correction needed.
- Depending on which side of the spine the point falls will indicate a positive or negative correction.
- How severe the correction will be depends on how far from the spine the point falls on a “rib”.

![Graph showing density sensor theory](image)
Compensated Spectral Density with robust spine-and-rib compensation.

Azimuthal binning for borehole imaging and logging in enlarged holes or w/ bi-center bits.

Compensated thermal neutron porosity with full environmental corrections

AZD and TNP sensor have the industry’s highest count rates for faster logging with better statistical precision.
As the tool rotates, X- and Y-axis magnetometers track the orientation of the detector blade.

Count rates are recorded every 25 milliseconds, and sorted into 16 azimuthal bins.

RHOB, DRHO, and Pe are computed for each of the 16 bins.
The 16 azimuthally oriented density curves... are interpolated vertically and circumferentially to produce a 360° borehole image. Dips are computed from planar features picked on the image log.
AZD Image with Fault
<table>
<thead>
<tr>
<th>Curves</th>
<th>Static Density Image (2.5 - 3.0 g/cc)</th>
<th>Density Standoff Image (0 - 0.75 inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma Ray</td>
<td>DRHO</td>
<td>AZI_LSSRHOZC</td>
</tr>
<tr>
<td></td>
<td>API</td>
<td></td>
</tr>
<tr>
<td>S_ROP</td>
<td>m/hr</td>
<td></td>
</tr>
<tr>
<td>BSIZE</td>
<td></td>
<td>RHOZC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AZI_LSSOFFZ</td>
</tr>
</tbody>
</table>

**Reduced ROP**

**Borehole Spiraling**
AZD image showing stress-induced borehole breakout
AZD Summary

• Environment: 165°C (329°F), 30,000 psi

• Tool Sizes: 4-3/4”, 6-3/4”, 8-1/4”

• Output:
  – RHOB, DRHO, Pe, CALI Curves
  – Quadrant RHOB, DRHO, PE, Standoff, RHOss
  – 16-Bin RHOB, DRHO, PE, Standoff, RHOss (Real-Time & Recorded)

• Applications:
  – Geosteering
  – Structural Dip Information
  – Accurate Density in enlarged boreholes
  – Borehole shape image from standoff
    • Spiraling, breakout, packer placement, etc.
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Neutron Porosity Measurement

Far Detector → Neutron Source
Near Detector → Neutron Source

Fast Neutrons released
Thermal Neutrons return
Neutron Porosity Measurements

• Source Emits Fast Neutrons (High Energy)

• Neutrons Travel through the formation and BoreHole

• Hydrogen moderates and slows the neutrons

• Hydrogen depends on Quantity of Oil and Water

• Higher the porosity lesser number of Neutrons reach the Detector

• Ratio of counts on Near and Far Detector gives Thermal Porosity
Thermal Neutron Porosity Corrections

Five parameters to correct for: borehole size, borehole temperature, mud hydrogen index (HI), borehole and formation salinity

- **Borehole size**: the larger the hole size, the higher the apparent porosity
- **Borehole temperature**: the higher the temperature, the lower the apparent porosity
- **Mud HI**: the higher the mud HI, the higher the apparent porosity
- **The borehole and formation salinity**: the higher the salinity (Chlorine content) the higher the apparent porosity
TNP Specifications and Features

• Environment: 165°C, 30,000 psi

• Detector configuration optimized for each tool size (4-3/4”, 6-3/4”, & 8-1/4”)
  – Higher count rate / better statistical precision
  – Better formation sensitivity
  – Minimized environmental effects

• Statistical precision better than wireline for drilling rates up to @ 400 ft/hr

• Complete Environmental Corrections, including:
  – Hole size and standoff
  – Formation matrix capture cross section
  – Separate mud weight corrections for barite, hematite, and calcite
  – Mud weight & salinity, press. & temp., fm. salinity, lithology
Gas / Water Contact
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Shockwave Sonic Tool

- 6 Receivers
- Unique, highly effective attenuator section
- Unique, powerful transmitter

6 in. to 6 ft.
Shockwave Sonic

• **Features:**
  – Powerful transmitter
  – High-effective attenuator eliminates tool mode
  – Superior signal/noise ratio
  – Two real-time options:
    • Downhole-computed slowness values,
    • Real-time coherence VDL for surface labeling

• **Applications:**
  – Seismic time-depth correlation
  – Porosity measurement
  – Real-time pore pressure evaluation
  – Rock mechanics for drilling, completion, and stimulation
  – Wireline replacement
Real-Time Quad-Combo: Δt Picked from Real-Time Coherence VDL
<table>
<thead>
<tr>
<th>Slowness</th>
<th>Semblance</th>
<th>Waveform VDL</th>
<th>Waveforms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DTC</td>
<td></td>
<td>R1WVF</td>
</tr>
<tr>
<td>40 us/ft</td>
<td>DTS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
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</tr>
</tbody>
</table>

**North Sea - Through 9-5/8" Casing**
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• PressureWave Formation Tester
PressureWave – Formation Pressure Tester

- Formation tester uses unique downhole processing logic to ensure maximum data value from each pre test
- Minimising on station time – reducing risk
- On station pulser moves to high data rate pressure only data
- Tool can operate pumps on or off
Field Test

Test #33 - Real Time & Recorded

Time (sec)

Pressure - Recorded (psia)

Real Time Data

FTQPress

FTQPress Smoothed
Any Questions