TIME MATTERS:

Short-Time-Span Petrophysical and Formation Properties Variation

Presentation prepared for the Denver DWLS by John Priest, Elton Frost, Terrence Quinn
We observed short term variations in several petrophysical and formation properties over a twenty-eight day span.

This twenty-eight day span started with cutting rock.

From measurements taken less than 1 hour after cutting rock to measurements spanning the next twenty-eight days we examine time-dependent data variations.

The full suite of measurements included LWD/MWD and wire line instruments: resistivity, gamma ray and density images, and porosity, resistivity and magnetic resonance data.

The analysis for this work will illustrate time-independent repeatability contrasted with time-dependent variations over various well segments and sensors. The time-independent repeatability provides a baseline for detecting and, eventually, quantifying those time-dependent variations.
Strategy

• Baseline tests
  – Exhibit repeatability over time
  – Where we have redundant data

• Time-dependency tests using multiple tools
  – Use instruments with confirmed repeatability
  – Use multiple passes through zone

• Examine and interpret time dependent responses
  – Borehole degradation
  – Breakouts
  – Drilling induced fractures
  – Fluid invasion
Beta Test Site, Well and Sample Lithology

Data from this well
Test Objectives

- Tool characterization
  - Depth of investigation
  - Repeatability
  - Resolution and calibration
  - Data quality
- Formation properties, ~2914 ft data
  - Log and core data comparisons
  - Unconventional resources
  - Porosity and permeability
- Core, 437.5 ft, ~133 m
- Core targets
  - Chelsea sandstone
  - Blue Jacket sandstone
  - Fayetteville shale
  - Woodford shale
  - Viola Limestone
  - Bromide tight sand
- Plan the logging runs
- Include re-logs
- Use multiple tools
- Establish time line and re-logs
- Preserve raw data
- Eliminate excessive processing
- Establish repeatability
- Demonstrate tool repeatability
- Guarantees changes not tool
- Establish time-dependent variation
- Examine cases with variation
- Capture events
- Interpret those events
Opportunity Profile

- Opportunities for time-variable logging
  - Whenever the bit is moved off bottom
  - Multiple opportunities for re-logging
- Time and planning are required
  - Time to do the log
  - Planned
    - Importance—key zones
    - When—if schedule permits
    - Where—zone of interest
  - Unplanned
    - Opportunistic
    - Be prepared, just in case
## High Resolution Data

<table>
<thead>
<tr>
<th>Auxillary</th>
<th>Resisitivity Caliper</th>
<th>Acoustic Caliper</th>
<th>Core Photographs at Bit</th>
<th>LWD Resistivity A</th>
<th>LWD Resistivity B</th>
<th>LWD Resistivity C</th>
<th>Pad Resistivity</th>
<th>Ultrasound Image</th>
<th>Ultrasound Caliper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclination</td>
<td>Rad 1 Rad 2 Rad 3</td>
<td>Rad 4 Rad 5 Rad 6</td>
<td>Rad 7 Rad 8 Rad 9 Rad 10</td>
<td>26 Hrs Behind Bit</td>
<td>27 Hrs Behind Bit</td>
<td>14 Days Behind Bit</td>
<td>28 days Behind Bit</td>
<td>28 days Behind Bit</td>
<td>29 days Behind Bit</td>
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<tr>
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</tr>
</tbody>
</table>

![Data visualization with various plots and graphs](image-url)
Low Resolution Data
Resistivity Baseline

In This Interval

Unchanging resistivity profile
- After 28 days
- Leads to the conclusion:
  - There is little or no invasion
  - Data is repeatable from LWD to Wireline

Note: Any depth offset between LWD and wireline data arises from using raw uncorrected data.

Our intent is to minimize data alterations for repeatability and variability analysis.
Resistivity Time Variable

In This Interval

- Invasion processes cause
  - Separation of deep to shallow resistivity curves
- Constant separation indicates
  - Rapid invasion process (not observed)
- Increasing separation indicates
  - Time dependent invasion
  - Invasion rate appears to be increasing
- Questions:
  - Mud system changing?
  - Permeability barrier changing?
  - Mud cake properties changing?
Nuclear Magnetic Resonance Baseline

- Similar results: LWD vs. wireline
- Tool design differences:
  - Wireline
    - One Pad integral to mandrel
    - Limited azimuthal range
    - Designed for low side
  - LWD
    - Rotating standoff measurement
    - Full rotational measurement

![Graph of $T_2$ (msec)]
Nuclear Magnetic Resonance Time Dependent

- 126 ft (~2 hr), 21 and 28 days later
- Borehole degradation differences
  - ~2 hr washout(?) at 1630 ft
  - Day 21 expands to 1590 ft
  - Consistent with day 28 density
- Tool design differences
  - Wireline, one pad
    - Limited azimuthal range
    - Reduces effect of probable washout
  - LWD, rotating tool
    - Full 360° borehole coverage
Repeatability

- **Two tools, two runs**
  - 1A 96.12 ft behind bit
  - 1B 104.37 ft behind bit
  - B-A 8.25 ft sensor spacing
  - Run 1 ➔ Run 2, 5 days later
- **Two RPM’s**
  - 60 RPM while drilling
  - 30 RPM for re-log
- **Two image orientations**
  - High side
  - Magnetometer reference
- **Both logs ROP ~70 ft/hr**
- **Data from tool memory**

Note: Raw data—depth and data orientation as recorded by acquisition system.
Is It Real?

• Whenever we see the unusual:
  • We must ask:
    • “Is it real?”
    • “Will it repeat?”
    • “Does it repeat?”

• Two Tools
• One Run
• Sensor separation 8.25 ft (~2.5 m)

• The unusual repeated!

• Yes “It is Real.”
Visible Image Degradation

- Left, 72.7 ft, ~1 hour behind bit.
- Right, 8 days later
- On the basis of this image alone:
  - Can infer well bore degradation
  - Cannot prove well bore degradation
  - We cannot get caliper information

- All data is ‘as acquired’
- Only data correction applied
  - Block shift applied
  - Depth align the data for tool offset
  - Minimizes processing changes
- Shale core shows failure mechanism
How Can We Use Time-Lapse Data?

- N-8 well, LWD only
  - Days 1 and 12

- Using N-8 data with N-5 data
  - Predict day 25
    - Induction resistivity
    - Magnetic resonance
    - Neutron density
  - Prediction uses a geostatistical technique

Olivera, A., Dufour, J., Estimating Petrophysical Parameters from a Probabilistic Data Base
Non-Time Lapse Degradation

• Do you know what this shows?
Conclusions

• LWD advantages
  • LWD data is very repeatable
  • You cannot get closer to pristine well bore conditions

• Time lapse logging
  • Can be accomplished with LWD re-log data
  • Can be accomplished when tripping in or out

• Provides insight into:
  • Fluid invasion
  • Borehole stability
  • Borehole stability prediction for future wells

• Time lapse data variations seen on high and low resolution data
Now for Some Humor and Other Observations
Say Mac, Have we got our new coring system yet?
Borehole Integrity Matters

Say Mac, Who did the Porosity analysis on this?

Charlie, did you do the borehole stability analysis on this ahead of time, or did you use the Force?
Show This to the Anti-Frac’rs
Even Good Cores Show Fractures
Our thanks to the Denver DWLS for the honor of presenting our work

John Priest
Elton Frost
Terry Quinn