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Planning and Evaluating New Generation Pulsed Neutron Logs: An Example from Duvernay Shale

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Summary

Formation evaluation in cased wells may utilize new-generation slim pulsed neutron tools that record data based in the time domain or energy spectrum domain. It is uncommon that a single tool has so many options, often requiring special tool modes and log speeds. Careful job planning determines which measurements are required from the pulsed neutron tool, as well as special acquisition modes, log speeds or other parameters.

Time-domain based includes formation capture cross section (SIGMA) and thermal neutron porosity (TPHI). Energy-domain data is used to determine the dry weight elemental composition for mineralogy, and carbon which is sensitive to oil saturation from carbon to oxygen yield ratio (C/O), and Total Organic Carbon (TOC) used to determine kerogen volume. A new measurement is used to quantify gas volume from fast neutron cross section (FNXS).

Reservoir challenges, such as fresh formation water or complicated mineralogy determine what log measurements s are required. pre-job planning determines the tool acquisition modes and logging speed requirements. Good job execution and post job processing will ensure the appropriate and highest quality measurements are obtained. A typical job is examined here, from the Duverney field in Alberta.

Theory / Method / Workflow

Tool Description

Improvements have been made to both hardware and software. New measurements from a single pulsed neutron tool, better borehole characterization, and improved statistical precision are achieved.

New tools are NACE compliant for H_2S and CO_2 resistance, 1.72 in (4.37 cm) diameter, and rated to 175 °C and 15 kPSI (1.3.4 MPa).

Measurements are made from a high output pulsed neutron generator (PNG) and four detectors; one compact neutron monitor (CNM), two lanthanum bromide (LaBr3) gamma ray detectors, and a longer spaced yttrium aluminum perovskite (YAP) gamma ray detector.

Gamma Ray Time Spectra Data

Time spectra data is recorded at a relatively fast logging speed, usually over 1800 ft/hr, and a job requiring only this data often requires only a single pass Data collected includes SIGM and TPHI. A gamma ray (GR) and collar locator log (CCL) are typically recorded as well with every cased hole job. Fast Neutron Cross Section (FNXS) is a new measurement that is sensitive to gas volume in the

formation. It is determined from recording inelastic gamma rays from the farthest spaced detector and is independent of TPHI and SIGMA.

Inelastic and Capture Spectroscopy Data

Logging speeds required to obtain data in the energy spectra domain are much slower than time domains. Historically, energy and time domain data required separate tool acquisition modes and passes. However, with new-generation tools it is possible to obtain all data in a single log pass. Logging speeds depend on the reservoir environment and precision required.
Elemental dry weights concentrations are computed for elements that typically include Ca,Si,S,Fe,Ti,Gd, Mg and C. This data is used to determine the formation mineralogy and total organic carbon (TOC). An alternate processing method is available to determine oil saturation (So) from the C/O ratio.

Workflow

A workflow is shown below and uses a case study from Canada Duverney as example.

1. Determination of Required Measurements

Table 1. below shows some specific conditions that may guide selection of slim pulsed neutron measurements.

Measure	Fresh Water	Oil	Gas	TOC	Kerogen	Carbonate Complex Lith	Standalone	Tight Low Poro	Comments
TPHI	X	X	X	X	X	X	X	X	Always
SIGM	X	X	X	X	X	X	X	X	Recommended
FNXS			X						Gas Evaluation
Dry Weights						X	X	X	**Slow Speed**
C, C/O, Mg, K, Al	X			X	X		X	X	**Very Slow Speed**

Table 1. Recommended pulsed neutron modes for reservoir conditions

2. Select Acquisition Parameters

Modelling software is used to estimate precision of required measurements. Time spectra data is typically logged 1,800 ft/hr or higher. A Duvernay example is shown that requires high precision spectroscopy data. Table 2. Shows the effect of log speed and depth averaging on modeled precision.

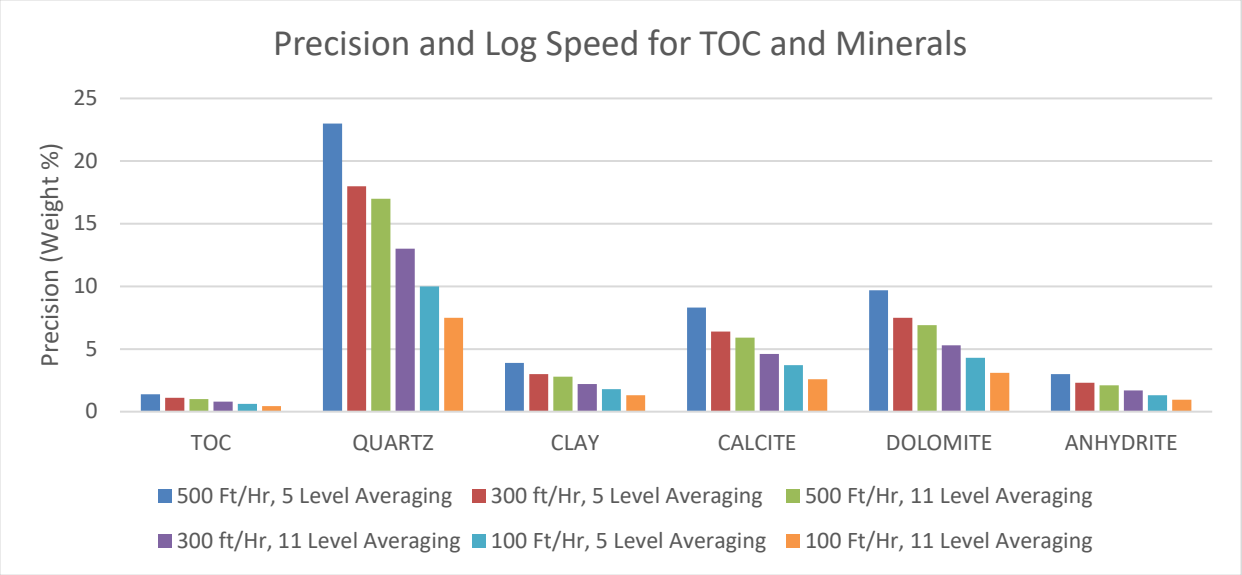

Table 2. Precision of TOC and minerals for a Duverney model formation of 7 pu mixed sand/lime formation, 156mm bit size and 114mm , 22.47 lb/ft casing.

3. Data Quality and Control
   Real time monitoring by the logging engineer or offsite specialist is facilitated by special log formats showing tool power, PNG and detector voltages and currents, and other critical tool information that ensures the tool is functioning properly.

4. Data Processing
   Post job processing of data ensures the highest quality of results are obtained. Processing is required on the following measurements
   a. FNXS
   b. Inelastic and capture Spectral Stripping and Closure

5. Petrophysical Interpretation
   A multimineral linear solver is used to incorporate the various measurements and determine complex lithology, porosity and saturation.

Results, Observations, Conclusions

In this example, time based and energy spectra domain data from the pulsed neutron tool was acquired and analyzed.

Results are shown in Figure 1. Lithology, porosity, and hydrocarbon saturation are determined and show variation along the lateral well. In this example, acoustic data is also collected to determine rock mechanical properties for completions quality estimation.

The mineralogical model in this example computed volumes of Illite, quartz, calcite, kerogen, gas and water. Total and effective porosity, saturation and other petrophysical properties are used to evaluate the reservoir quality along the lateral well.

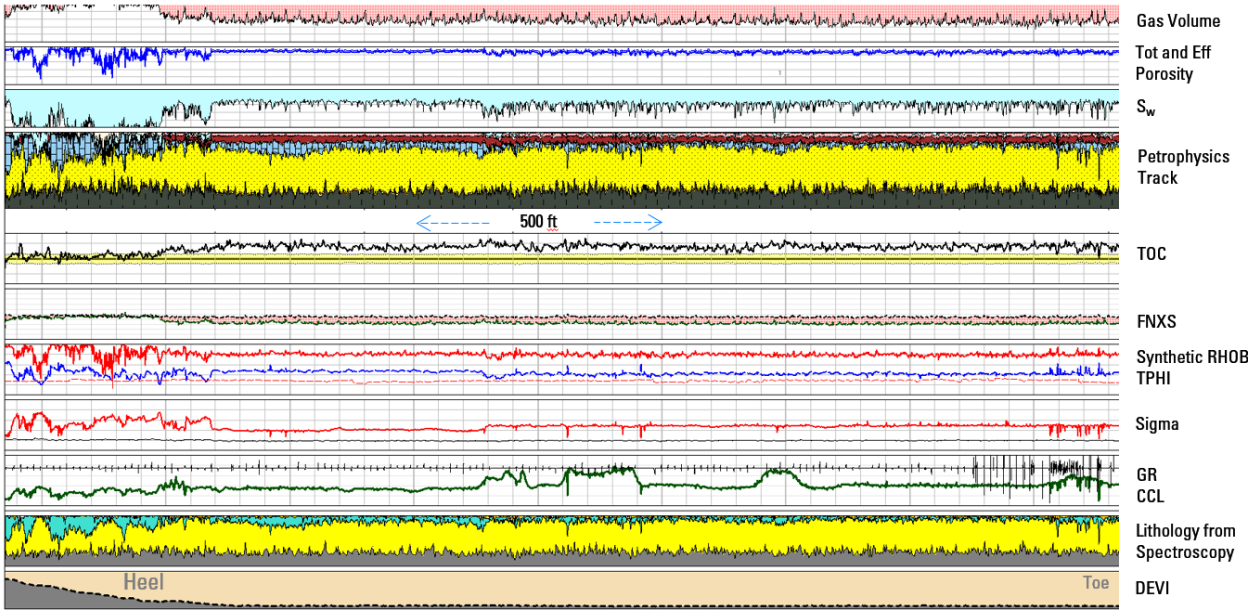

Figure 1. Pulsed Neutron evaluation using time domain and energy spectra data. Logging speed was 300 ft/hr with 11 level vertical averaging of depth levels.

Novel/Additive Information

Using this work flow, additional measurements that are not available such as bulk density may be reconstructed in the linear solver.

In gas reservoirs, incorporating FNXS help in determining the true porosity when only thermal neutron porosity is available, which under calls in gas zones.

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