ELAN Petrophysical Analysis Report
Danielson 33-17

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1 Executive Summary/Introduction

A petrophysical interpretation of wireline measured data was processed using Quanti.Elan* multicomponent inversion solver program within Techlog* wellbore software platform. Quanti.Elan uses the response equation for each of the wireline tool measurements to produce an advanced multimineral log analysis by optimizing these equations simultaneously as described by one or more interpretation models. The resulting analysis provides key petrophysical answers that describe the formation which the borehole intersects. Answers derived from this analysis include but are not limited to porosity, lithology, and permeability. This report describes the products and input parameters used in the Quanti.Elan analysis.

2 Logging Program

The table below identifies the logging runs made by date and depth, the tools included in each run, and the primary reason for running that logging tool.

The following tools were used and the tool names are listed in Table 1.
AIT* array induction imager tool
CMR* combinable magnetic resonance tool
ECS* elemental capture spectroscopy sonde
FMI* fullbore formation microimager
GPIT* general purpose inclinometry tool
GR - gamma ray
HNGS - hostile environment natural gamma ray spectroscopy sonde
HRLA* high-resolution laterolog array tool
Platform Express* integrated wireline logging tool
PPC - Powered Position Caliper
Sonic Scanner* acoustic scanning platform

Table 1: Logging Tools by Run

Date / Depth	Logging Run	Logging tools	Data Used For
9 May 2014 **263 – 1,900 feet**	**Platform Express - Sonic Scanner - AIT-GR-PPC-GPIT**	• Density • Neutron Porosity • Array Induction Resistivity • Gamma Ray • Caliper • SP • Sonic Compressional and 3D Anisotropic Shear • Powered Position Caliper (4-arm caliper) • Inclinometry	• Correlation • Porosity • Saturation • Mechanical Properties • Seismic Tie Structure • Hole Size • Hole Direction

Date / Depth	Logging Run	Logging tools	Data Used For
16 May 2014 **1,900 – 3,800 feet**	**Platform Express – ECS – HRLA – AIT**	• Density • Neutron Porosity • Array Laterolog Resistivity • Gamma Ray • Caliper • SP • Elemental Capture Spectroscopy	• Correlation • Porosity • Saturations • Hole Size • Mineralogy • Clay
	Sonic Scanner – FMI-PPC-GPIT	• Sonic Compressional and 3D Anisotropic Shear • Formation Micro-Imager borehole images, • Powered Position Caliper (4-arm caliper) • Inclinometry	• Porosity • Mechanical Properties • Seismic Tie Structure • Environmental Deposition • Fractures • Hole Size • Hole Direction
	CMR – HNGS	• Magnetic Resonance • Spectral Gamma Ray	• Lithology Independent Porosity • Free and Bound Fluids • Permeability • Mineralogy • Clay

2.1 Summary of Table

A Platform Express standard run includes density, neutron porosity, resistivity, gamma ray, and caliper measurements and is run for basic petrophysical properties of porosity, lithology, volume of shale and saturations. Gamma ray and resistivity are also the primary measurements used for correlation to other wells. Either an array induction tool or array laterolog tool are used to measure the formation resistivity depending on the conductivity of the borehole mud, the conductivity of the formation and the hole size. ECS is used to quantify elements in the formation to solve for formation lithology and improve the clay volume, formation porosity and permeability estimation.

Sonic Scanner is an array sonic tool used to measure the compressional and anisotropic shear sonic velocities in the formation. These measurements can then be used to calculate sonic porosity, seismogram for seismic well tie and three dimensional (3D) acoustical characterization for anisotropic mechanical rock properties, stress direction and quantification, and velocity modeling for micro-seismic and improved seismic interpretation.

FMI provides high resolution borehole images used to identify structure, depositional environment and fractures that may be present in the formations as well as aiding in mechanical properties modeling.

CMR provides a lithology independent porosity and pore size distribution. The distribution of pore sizes can be subdivided into small pores containing bound fluid and larger pores primarily containing free fluid. This measurement is also used to calculate a continuous permeability based on porosity and the pore size distribution. The HNGS provides natural gamma ray spectroscopy to aid in the analysis of the clay quantification and types and special minerals containing potassium, thorium, and uranium.

3 General Interpretation of the Data

Following is a brief description of the data provided on the Quanti.Elan* advanced multimineral log analysis print and example shown in Figure 1.

3.1 ELAN Log Presentation

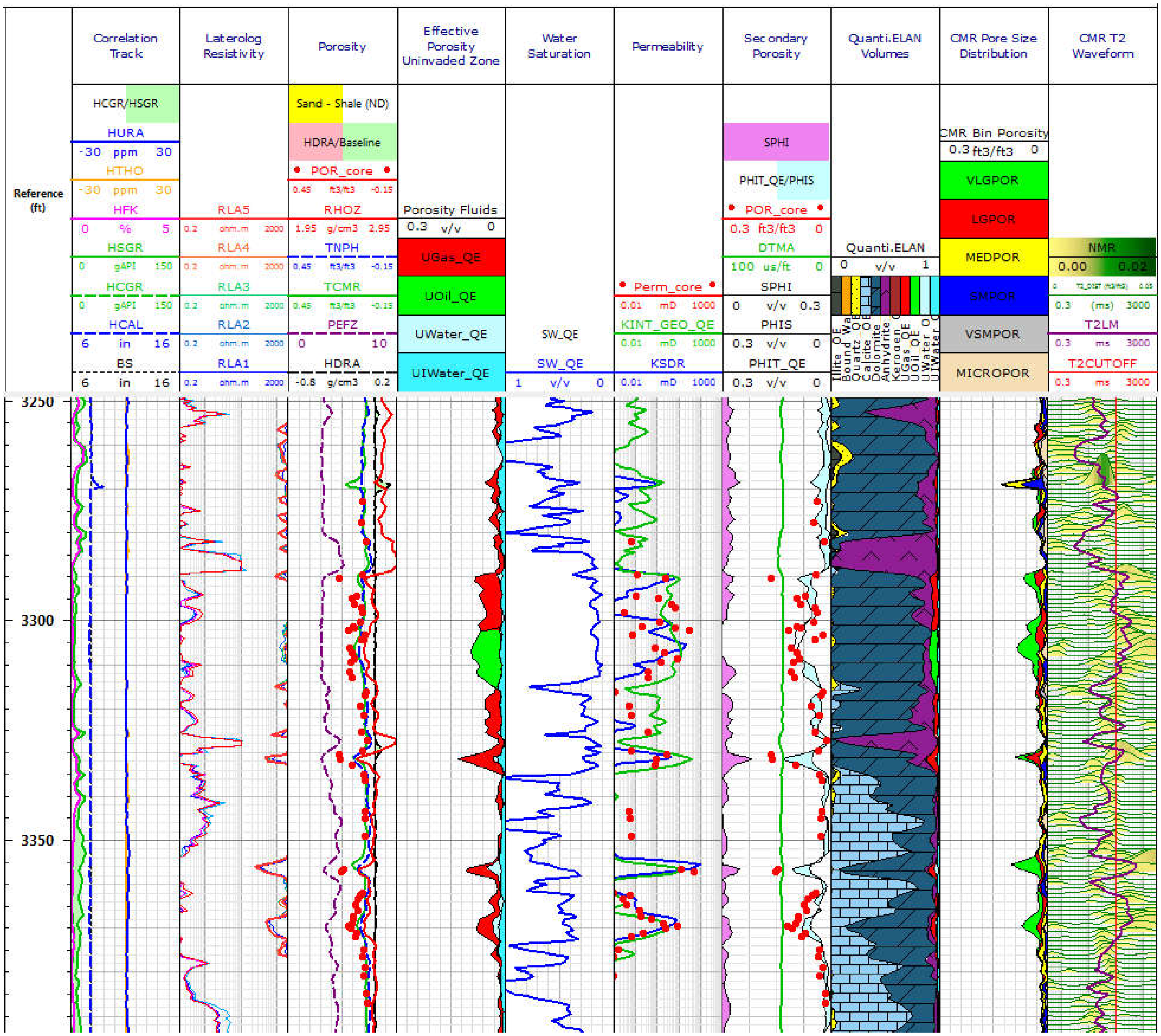

Figure 1: Danielson 33-17 Elan – portion of the Duperow formation

Track 1 – Depth Track

Depth Scale is 1:240 (5 in. / 100 ft.)

Track 2 – Correlation
HURA – HNGS Formation Uranium Concentration
HTHO – HNGS Formation Thorium Concentration
HFK – HNGS Formation Potassium Concentration
HSGR – Synthetic GR from HNGS Spectral Gamma Ray
HCGR – Gamma Ray minus uranium from HNGS Spectral Gamma Ray
HCAL – Hole size caliper from density caliper
BS – Bit Size

Track 3 – Resistivity
RLA5 to RLA2 – Array laterolog resistivity measurements with different depths of investigation. RLA5 is the deepest depth of investigation.

Track 4 – Porosity
POR_core – Core measured porosity
RHOZ – Bulk density of the formation. Bulk density is used in combination with the neutron and ECS spectrometry for porosity, lithology and identification of fluids.
TNPH – Environmentally corrected neutron porosity on a lime matrix. This is used in combination with the density and spectrometry tools for porosity, lithology and identification of fluids.
TCMR – CMR Total porosity form magnetic resonance.
PEFZ – Photoelectric Effect. This is an auxiliary measurement from the density tool used for lithology identification.
HDRA – Bulk density correction.

Track 5 – Uninvaded Zone Fluids
UGas_QE – Uninvaded zone free gas volume from Quanti.Elan model.
UOil_QE – Uninvaded zone free oil volume from Quanti.Elan model.
UIWater_QE – Uninvaded zone irreducible water volume (capillary bound) from Quanti.Elan model.
UWater_QE – Uninvaded zone free water volume from Quanti.Elan model.

Track 6 – Water Saturation
SW_QE – Water saturation uninvaded zone from Quanti.Elan model.

Track 7 – Permeability
Perm_core – Core measured permeability.
KINT_GEO_QE – Permeability estimated from K-Lamba, a geochemical and porosity estimation developed by Mike Herron, SPWLA 28th Annual Logging Symposium, London, June 1987." from Quanti.Elan model.
KSDR – Permeability estimated from the CMR using the SDR equation.

Track 8 – Secondary Porosity
POR_core – Core measured porosity.
DTMA – Sonic Delta-T matrix computed from Quanti.Elan lithology.
SPHI – Secondary porosity computed as sonic porosity, PHIS – total porosity, PHIT_QE.
PHIS – Sonic porosity computed from compressional slowness, DTCO and Delta-T matrix, DTMA.
PHIT_QE – Total porosity from Quanti.Elan model.

Track 9 – Quanti.Elan Volumes

Quanti.Elan mineral model displayed as mineral and fluid volumes displayed as volume percent. Minerals solved for were Clay (Illite), Quartz, Calcite, Dolomite, Anhydrite, and Kerogen. The fluids displayed are the uninvaded zone fluids gas (UGAS), oil (UOIL), moveable water (UWATER) and irreducible water (UIWATER).

Track 10 – CMR Bin Porosity

T2 relaxation time cutoffs used on total porosity measured by the CMR to bin the porosity into pores sizes from "micro-pores" to "very large pores".
VLGPOR – Very large pores.
LGPOR – Large pores.
MEDPOR – Medium pores.
SMPOR – Small pores.
VSMPOR – Very small pores.
MICROPOR – Micro pores.

Track 11 – CMR T2 Distribution

T2_DIST – Magnetic resonance T2 relaxation distribution of all fluids.
T2LM – Logarithmic mean of T2_DIST used in the SDR permeability estimation, KSDR.
T2CUTOFF – T2 cutoff separating small pores containing bound fluids < T2 cutoff and large pores containing free fluids > T2 cutoff used in the Timur-Coates permeability estimation, KTIM.

3.2 Quanti.Elan Model Description

Quanti.Elan is a software implementation of a volumetric analysis. It provides estimations of mineral volume fractions, fluid volumes, porosity, and permeability. Quanti.Elan uses an optimized simultaneous equation solver to derive the volume of each formation component first, then calculates a reconstructed property measurement from the known tool response to compare to the ELAN inputs. The petrophysicist optimizes the solution for the expected mineral and fluid volumes through iteration, adjusting weights and uncertainty of the inputs, and the mineral response parameters. Fluid saturations and an estimate of permeability are calculated from porosity, fluid and mineral volumes.

The inputs to the ELANPlus model were from the Platform Express, CMR, HNGS, SonicScanner, and ECS Spectrolith mineralogy. The Quanti.Elan model for formations below the Baken is shown in Table 2.

Table 2: ***ELAN Parameters for formations below the Baken***

	Illite (Clay)	Quartz	Calcite	Dolomite	Anhy-drite	XWater (flushed zone)	XOil (flushed zone)	XGas (flushed zone)	XIWater (flushed zone)	UWater (univaded zone)	UOil (univaded zone)	UGas (univaded zone)	UIWater (univaded zone)
Bulk Density (g/cm3)	2.79	2.65	2.71	2.87	2.98	1.0016	0.6	-0.0667	1.0095	1.0095	0.6	-0.0667	1.0095
Neutron Porosity (ft3/ft3)	0.3	-0.027	0	0.0099	-0.03	1	.8	0.1972	1	1	.8	0.1972	1
Sonic Scanner Delta-T (us/ft)	90	55.5	47.5	43.5	50	189	210	265	189	189	210	265	189
Porosity (v/v)	0	0	0	0	0	1	1	1	1	1	1	1	1
Volumetric Photoelectric Factor (b/cm3)	9.9	5	14.1	9.1	14.95	0.4357	0.11	0.015	0.4842	0.4842	0.11	0.015	0.4842
HNGS Thorium Concentration (ppm)	11.81	0	0	0	0	0	0	0	0	0	0	0	0
HNGS Potassium Concentration (%)	4.32	0	0	0	0	0	0	0	0	0	0	0	0
ECS Spectrolith Anhydrite Weight Fraction (lbf/lbf)	0	0	0	0	1	0	0	0	0	0	0	0	0
ECS Spectrolith Carbonate Weight Fraction (lbf/lbf)	0	0	1	1	0	0	0	0	0	0	0	0	0
ECS Spectrolith Clay Weight Fraction (lbf/lbf)	1	0	0	0	0	0	0	0	0	0	0	0	0
ECS Spectrolith QFM Weight Fraction (lbf/lbf)	0	1	0	0	0	0	0	0	0	0	0	0	0
HNGS GR minus Uranium (gAPI)	275	10	8	5	5	0	0	0	0	0	0	0	0
CMR Bound Water Volume (v/v)	0	0	0	0	0	0	0	0	1	0	0	0	1

The Quanti.Elan water saturation model used was Dual Water with the parameters m=2.2, n=2 and a=1. The Platform Express shallow resistivity, RLA1, was used to solve for the invaded zone water saturation and the deep resistivity, RLA5, for the uninvaded zone water saturation. Pickett Plots and the guide Sxo > Sw were used to find the formation water salinity, and the final model used 20 kppm for the Baken formation and below. This salinity estimate is dependent on the saturation equation parameters, mainly m and a, and therefore has a very high uncertainty. The same water saturation would be calculated from any reasonable formation water salinity by adjusting the water saturation equation parameters.

The Quanti.Elan post processing uses the ELANPlus volumetric model and calculates grain density and a permeability estimate. The permeability estimate called KINT_GEO_QE, is from K-Lamba, a porosity and mineralogy model. The K-Lamba model uses a “perm factor” for each mineral volume combined with the porosity to estimate permeability. This model was developed by Mike Herron et al and details of the procedure can be found in the paper listed in the reference.

CMR provides a pore size porosity distribution in addition to the total porosity. This pore size distribution can be divided into free fluid and bound fluid by using small pores as bound fluids, either clay or capillary, versus the large pores having free fluids. The pore size distribution and total porosity are used to estimate permeability. The two common magnetic resonance permeability equations are Timur-Coates and SDR (Schlumberger-Doll Research). The Timur-Coates equation uses a “cutoff” on the T2 distribution to partition bound and free fluid porosity. The SDR equation uses the geometric mean of the T2 distribution to estimate the permeability. The two CMR permeability estimates agreed with the trend of the ELAN K-Lamba permeability and reasonably well with the magnitude.

Routine core analysis (RCA) were performed on 67 samples from Duperow middle and top formations core. The routine core analysis provide porosity, grain density and permeability measurements to compare and calibrate the ELAN model. The total porosity from RCA agreed well with the Quanti-ELAN total porosity. Nitrogen permeability was performed on the RCA cores and used to calibrate the ELAN permeability estimate. The K-Lamba perm factors were adjusted to get the best fit in the RCA permeability.

3.3 Quanti.Elan Glossary

Anhydrite_QE	.v/v	: Anhydrite Volume Fraction
Bound_Water_QE	.v/v	: Clay Bound Water Volume Fraction
BS	.in	: Bit Size
Calcite_QE	.v/v	: Calcite Volume Fraction
Dolomite_QE	.v/v	: Dolomite Volume Fraction
DTCO	.us/ft	: SonicScanner Delta-T Compressional
DTMA	.us/ft	: Delta T matrix calculated from ELAN lithology
GR	.gAPI	: Gamma Ray
HCAL	.in	: Hole Diameter from Density Caliper
HCGR	.gAPI	: HNGS Computed Gamma Ray (HSGR minus Uranium)
HDRA	.g/cm3	: Density Standoff Correction
HFK	.%	: HNGS Formation Potassium Concentration
HSGR	.gAPI	: HNGS Standard Gamma-Ray
HTHO	.ppm	: HNGS Formation Thorium Concentration
HURA	.ppm	: HNGS Formation Uranium Concentration
Illite_QE	.v/v	: Illite Volume Fraction
Kerogen_QE	.v/v	: Kerogen Volume Fraction
KINT_GEO_QE	.mD	: Intrinsic permeability (Herron 1987 algorithm)
KSDR	.mD	: CMR Permeability estimated with SDR equation
LGPOR	.ft3/ft3	: CMR Large pores
MEDPOR	.ft3/ft3	: CMR Medium pores
MICROPOR	.ft3/ft3	: CMR Micro pores
PEFZ	.	: Formation Photoelectric Factor
PHIS	.v/v	: Sonic porosity
PHIT_QE	.v/v	: Total Porosity {F}
PIGN_QE	.v/v	: Effective porosity (Total Porosity – clay bound water)
Quartz_QE	.v/v	: Quartz Volume Fraction
RHOZ	.g/cm3	: Formation Density
RLA1	.ohm.m	: Apparent Resistivity from Computed Focusing Mode 1
RLA2	.ohm.m	: Apparent Resistivity from Computed Focusing Mode 2
RLA3	.ohm.m	: Apparent Resistivity from Computed Focusing Mode 3
RLA4	.ohm.m	: Apparent Resistivity from Computed Focusing Mode 4
RLA5	.ohm.m	: Apparent Resistivity from Computed Focusing Mode 5

SMPOR	.ft3/ft3	: CMR Small pores
SPHI	.v/v	: Secondary porosity computed as sonic porosity, PHIS – total porosity, PHIT_QE
SW_QE	.v/v	: Undisturbed Zone Water Saturation
T2LM	.ms	: CMR T2 Logarithmic Mean
TCMR	.ft3/ft3	: Total CMR Porosity
TNPH	.ft3/ft3	: Thermal Neutron Porosity, Limestone Lithology
UGas_QE	.v/v	: Undisturbed Zone Gas Volume Fraction
UIWater_QE	.v/v	: Undisturbed Zone Irreducible Water Volume Fraction
UOil_QE	.v/v	: Undisturbed Zone Oil Volume Fraction {F}
UWater_QE	.v/v	: Undisturbed Zone Water Volume Fraction {F}
VLGPOR	.ft3/ft3	: CMR Very Large pores
VSMPOR	.ft3/ft3	: CMR Very Small pores
WCAR_WALK2	.lbf/lbf	: Dry Weight Fraction Carbonate
WCLA_WALK2	.lbf/lbf	: Dry Weight Fraction Clay
WQFM_WALK2	.lbf/lbf	: Dry Weight Fraction Quartz+Feldspar+Mica (QFM)

3.4 References

Herron, M. M. (1987, January 1). Estimating the Intrinsic Permeability of Clastic Sediments from Geochemical Data. Society of Petrophysicists and Well-Log Analysts.

Herron, M. M., Johnson, D. L., & Schwartz, L. M. (1998, January 1). A Robust Permeability Estimator for Siliciclastics. Society of Petroleum Engineers. doi:10.2118/49301-MS