Petrophysical Analysis of the Bakken Interval, Nance Petroleum, Larson 11-26 Well, Richland County, Montana

Prepared for the Bakken Short Course
Rocky Mountain Section of the AAPG
Jackson, Wyoming

September 24, 2005

Digital Formation, Inc.

Outline

- Goals of the Study
- Data Available
- Basic Petrophysical Interpretation
- Core/Log Comparisons
- Fracture Analysis
- Permeability Modeling
- Pseudo Logs and Mechanical Properties
- Total Organic Carbon
- Conclusions

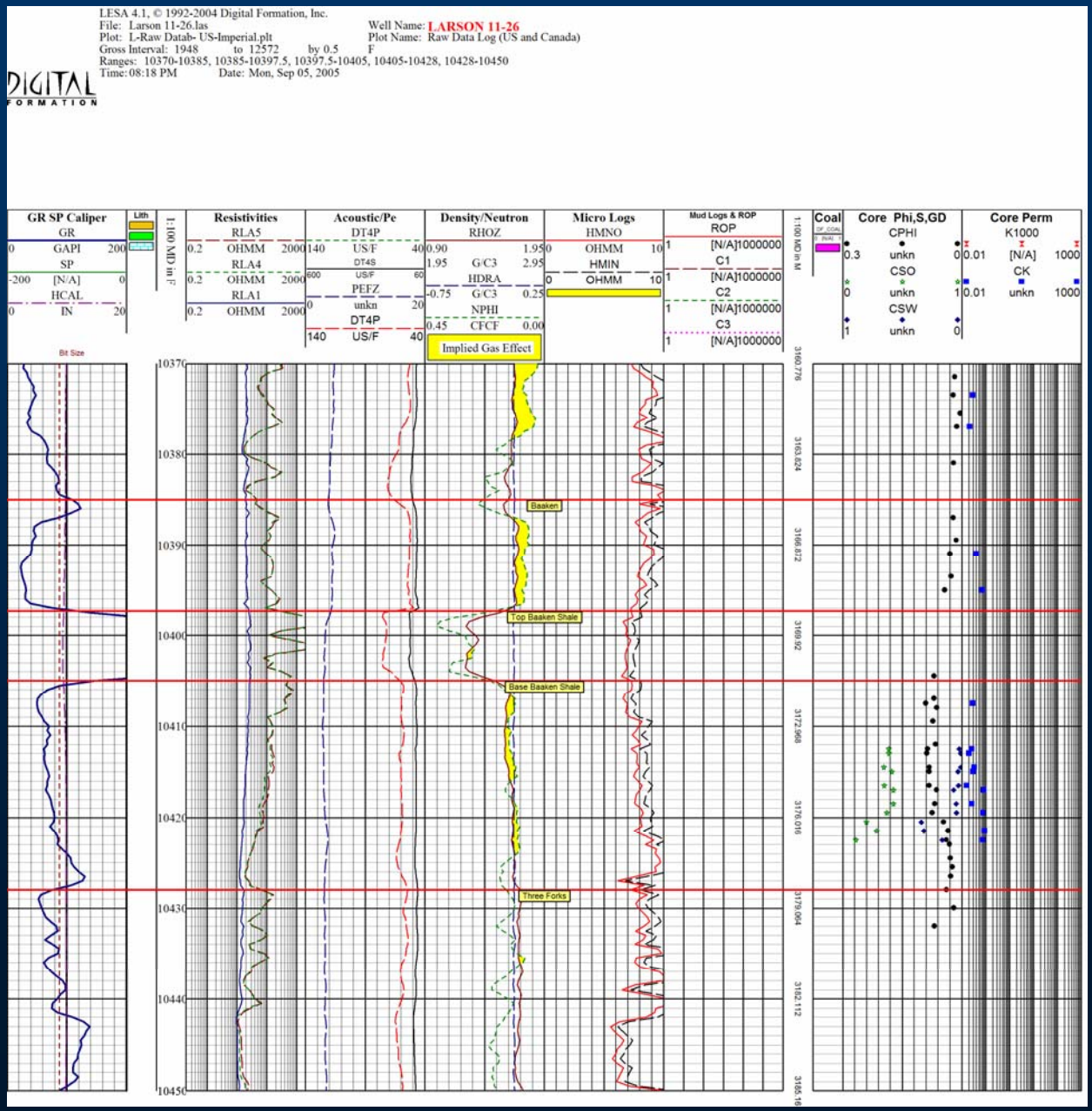
Goals of the Study

- To determine a petrophysical porosity/saturation model and compare with core measurements. Rocks are low porosity and very low permeability dolomitic limestones
- Examine if the reservoir is fractured
- Examine mechanical properties and define differences (if any) between the Bakken producing interval and intervals both above and below – examine barriers to fracture propagation
- Evaluate the Bakken Shale for total organic carbon and Pyrolosis S2 values – using the technique of Passey et al

Data Available

- Logs
  - GR
  - Array Resistivity
  - Acoustic Compressional and Shear
  - Pe
  - Density
  - Neutron
  - Microlog
- Formation Tops
- Core Data
  - Porosity
  - Dry Bulk Density
  - Grain Density
  - Gas Permeability
  - Water Saturation
  - Oil Saturation
  - Comments – particularly whether or not the permeability measurements are valid
- Recent wells (lateral) in the area have produced 342 BOPD and 480 BOPD

Raw Data Logs



Core Data

Nance Petroleum
Bakken Dolomite
Routine Core Analysis Test Results
Project No: 500947
January 23, 2004

TerraTek

Sample Number	Sample Depth (ft)	Sample Length (in)	Sample Diameter (in)	Ambient Porosity (%)	Dry Bulk Density (g/cc)	Grain Density (g/cc)	Gas Permeability (md)	Saturation		Comments
								Water (%)	Oil (%)	
1	10371.40	0.729	1.509	1.81	2.645	2.694	<0.01	*	*	
2	10373.60	0.804	1.509	2.17	2.639	2.697	0.028	*	*	Microfractured - Steady State Perm Invalid
3	10375.70	0.818	1.509	0.46	2.687	2.700	<0.01	*	*	
4	10377.20	0.886	1.509	1.24	2.660	2.694	0.021	*	*	
5	10379.80	shale								
6	10381.20	0.794	1.509	2.01	2.621	2.675	<0.01	*	*	
7	10383.70	shale								
8	10385.60	shale								
9	10387.00	0.850	1.509	2.20	2.686	2.747	<0.01	*	*	
10	10389.50	0.819	1.509	1.42	2.694	2.733	<0.01	*	*	
11	10391.20	0.856	1.509	2.98	2.640	2.721	0.040	*	*	Microfractured - Steady State Perm Invalid
12	10393.30	0.903	1.509	2.73	2.666	2.741	<0.01	*	*	
13	10395.20	0.676	1.509	4.33	2.624	2.743	0.071	*	*	Microfractured - Steady State Perm Invalid
14	10397.60	shale								
15	10405.40	0.830	1.509	6.95	2.608	2.803	<0.01	*	*	
16	10406.80	0.803	1.509	6.96	2.585	2.778	<0.01	*	*	
17	10407.40	0.801	1.509	9.10	2.518	2.770	0.028	*	*	Microfractured - Steady State Perm Invalid
18	10408.20	0.768	1.509	6.33	2.608	2.785	<0.01	*	*	
19	10409.40	0.823	1.509	7.24	2.551	2.750	<0.01	*	*	
20	10411.80	0.747	1.509	6.66	2.606	2.792	<0.01	*	*	
21	10412.70	0.742	1.509	8.61	2.517	2.754	0.026	2.14	38.45	
22	10413.20	0.880	1.508	8.81	2.526	2.769	0.020	0.88	38.65	
23	10414.50	0.690	1.495	8.20	2.530	2.756	0.033	1.23	34.52	Microfractured - Steady State Perm Invalid
24	10415.20	0.651	1.509	8.24	2.544	2.773	0.030	3.18	41.00	
25	10416.30	0.704	1.509	8.27	2.556	2.786	0.016	2.93	34.65	
26	10417.20	0.779	1.510	6.35	2.580	2.755	0.081	6.89	42.36	Microfractured - Steady State Perm Invalid
27	10418.40	0.710	1.509	6.85	2.578	2.767	0.025	4.91	42.40	Microfractured - Steady State Perm Invalid
28	10419.30	0.792	1.509	7.50	2.578	2.787	0.074	4.60	37.12	Microfractured - Steady State Perm Invalid

Core Data - continued

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Bakken Dolomite
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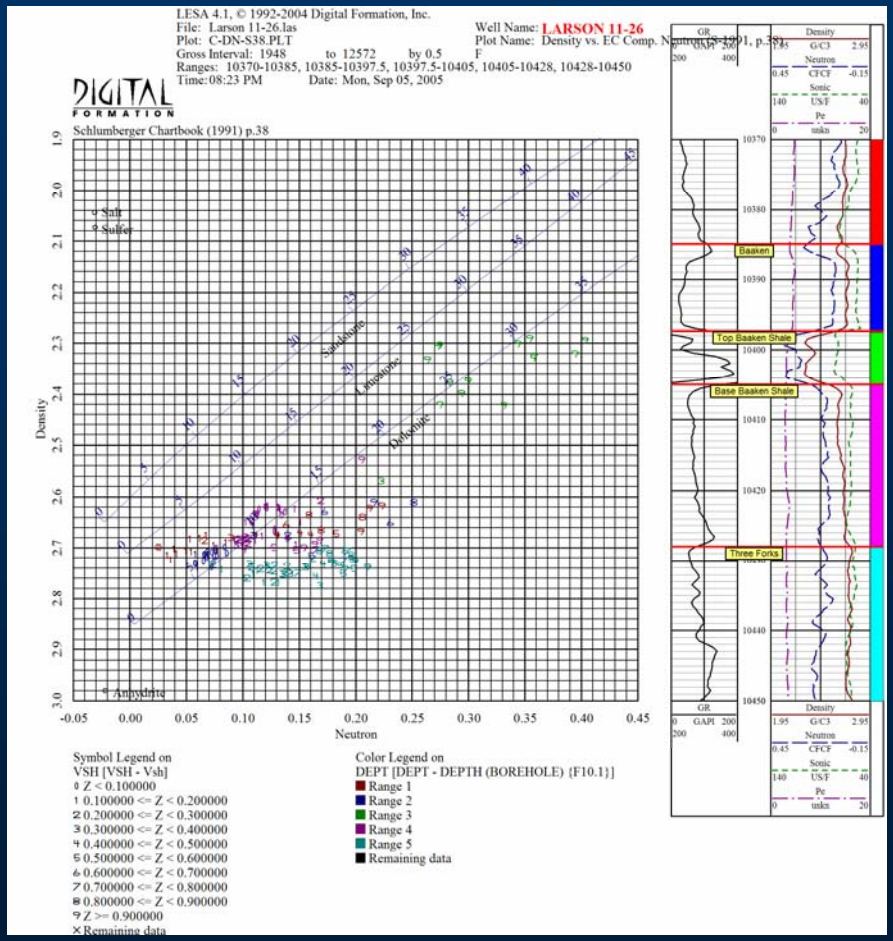
TerraTek

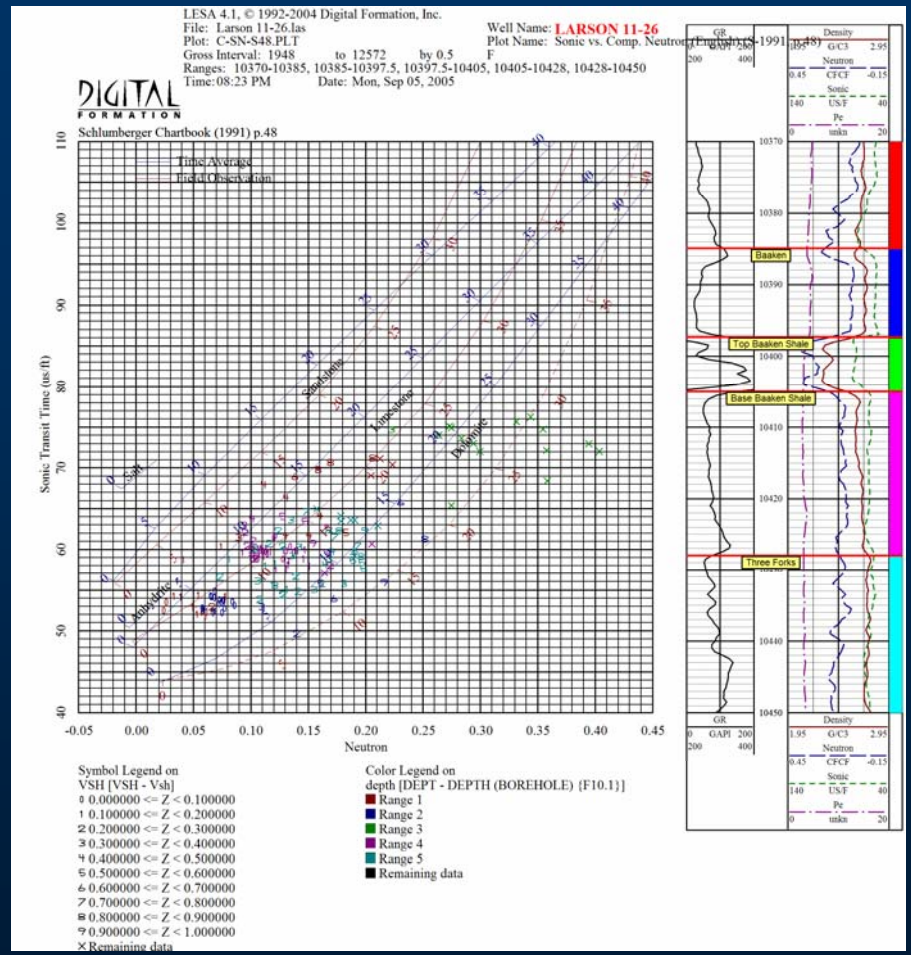
Sample Number	Sample Depth (ft)	Sample Length (in)	Sample Diameter (in)	Ambient Porosity (%)	Dry Bulk Density (g/cc)	Grain Density (g/cc)	Gas Permeability (md)	Saturation		Comments
								Water (%)	Oil (%)	
29	10420.30	0.758	1.509	4.62	2.614	2.741	0.299	34.10	19.81	Microfractured - Steady State Perm Invalid
30	10421.40	0.772	1.509	3.46	2.627	2.722	0.090	31.94	28.43	Microfractured - Steady State Perm Invalid
31	10422.50	0.788	1.509	3.88	2.618	2.724	0.073	16.75	10.95	Microfractured - Steady State Perm Invalid
32	10423.20	0.790	1.509	3.12	2.636	2.721	2.551	*	*	Coring Induced MicroFractured -SS K invalid
33	10424.60	0.770	1.509	2.93	2.637	2.717	0.435	*	*	Microfractured - Steady State Perm Invalid
34	10425.30	0.802	1.509	2.42	2.642	2.708	3.026	*	*	Coring Induced MicroFractured -SS K invalid
35	10426.60	0.750	1.509	2.76	2.634	2.709	9.318	*	*	Coring Induced MicroFractured -SS K invalid
36	10428.20	0.730	1.509	3.92	2.634	2.742	0.891	*	*	Microfractured - Steady State Perm Invalid
37	10430.20	0.814	1.509	2.02	2.740	2.797	<0.01	*	*	Microfractured - Steady State Perm Invalid
38	10432.20	0.816	1.509	6.92	2.614	2.809	0.478	*	*	Microfractured - Steady State Perm Invalid
39	10433.80	Mixed Shale								

* Dean Stark analysis is invalid based on original samples tested with the possible exception of sample number 29 which appeared to have similar results to the retort data and is likely one of the most permeable samples.

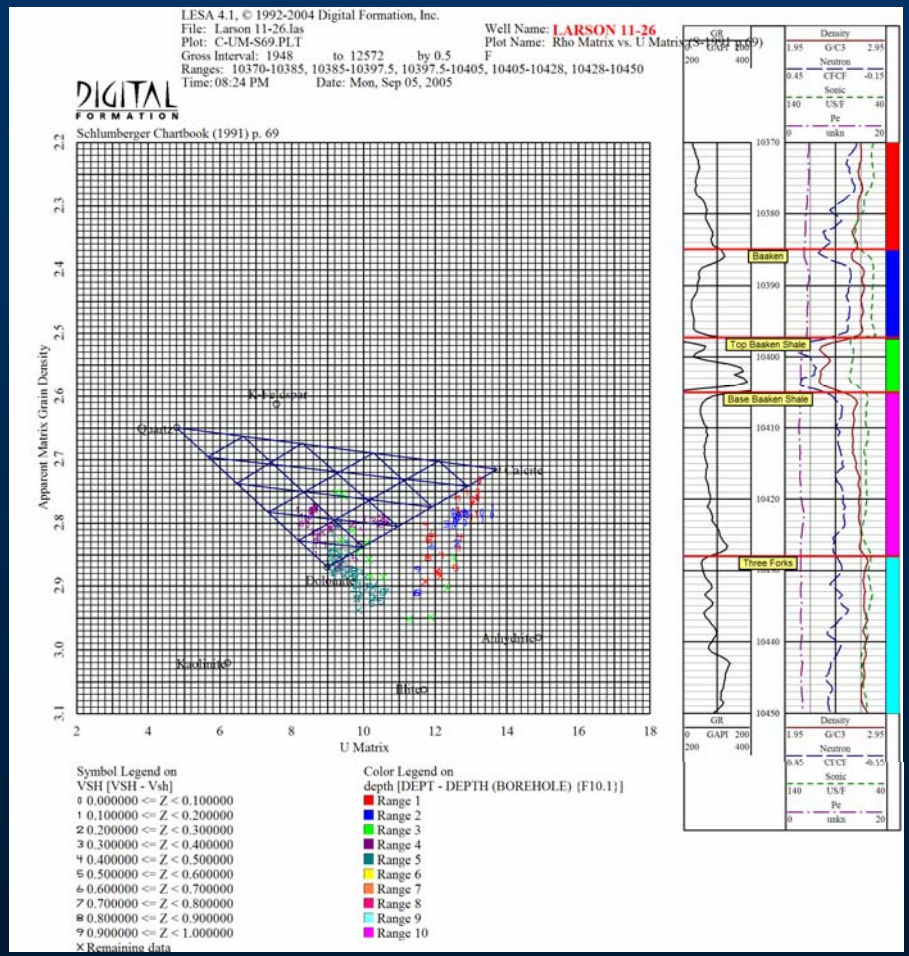
Density/Neutron



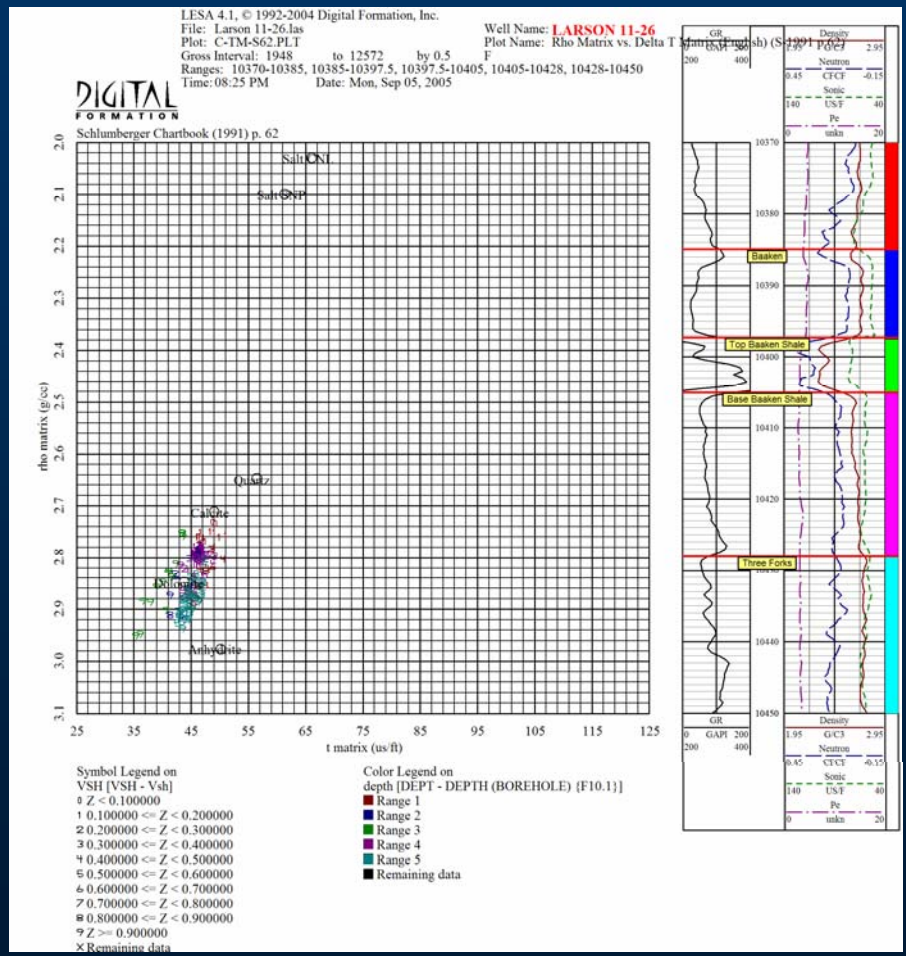
Density/Sonic



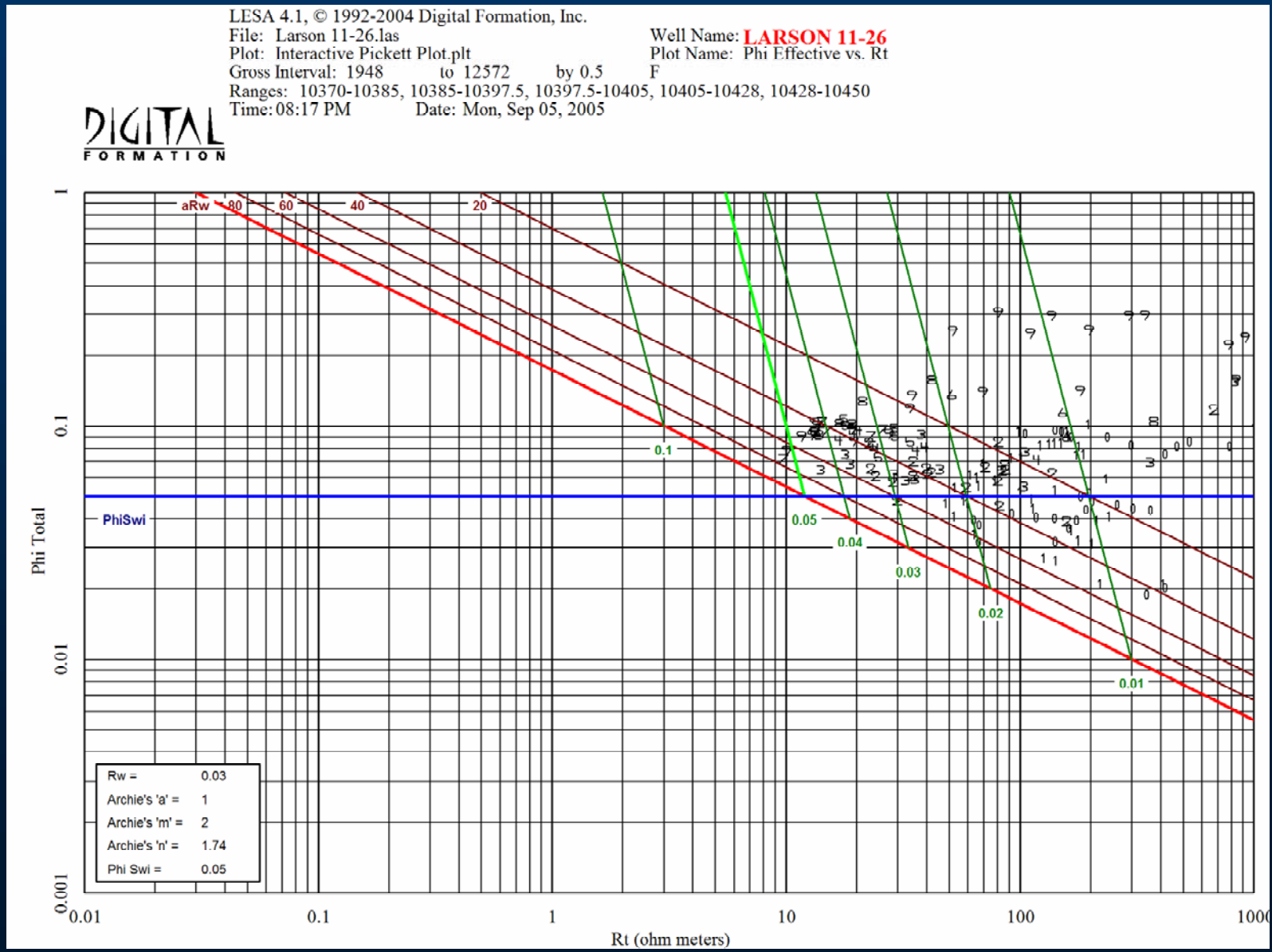
U_{matrix} vs. Rho_{matrix}



Rho_{matrix} vs. Delta T_{matrix}

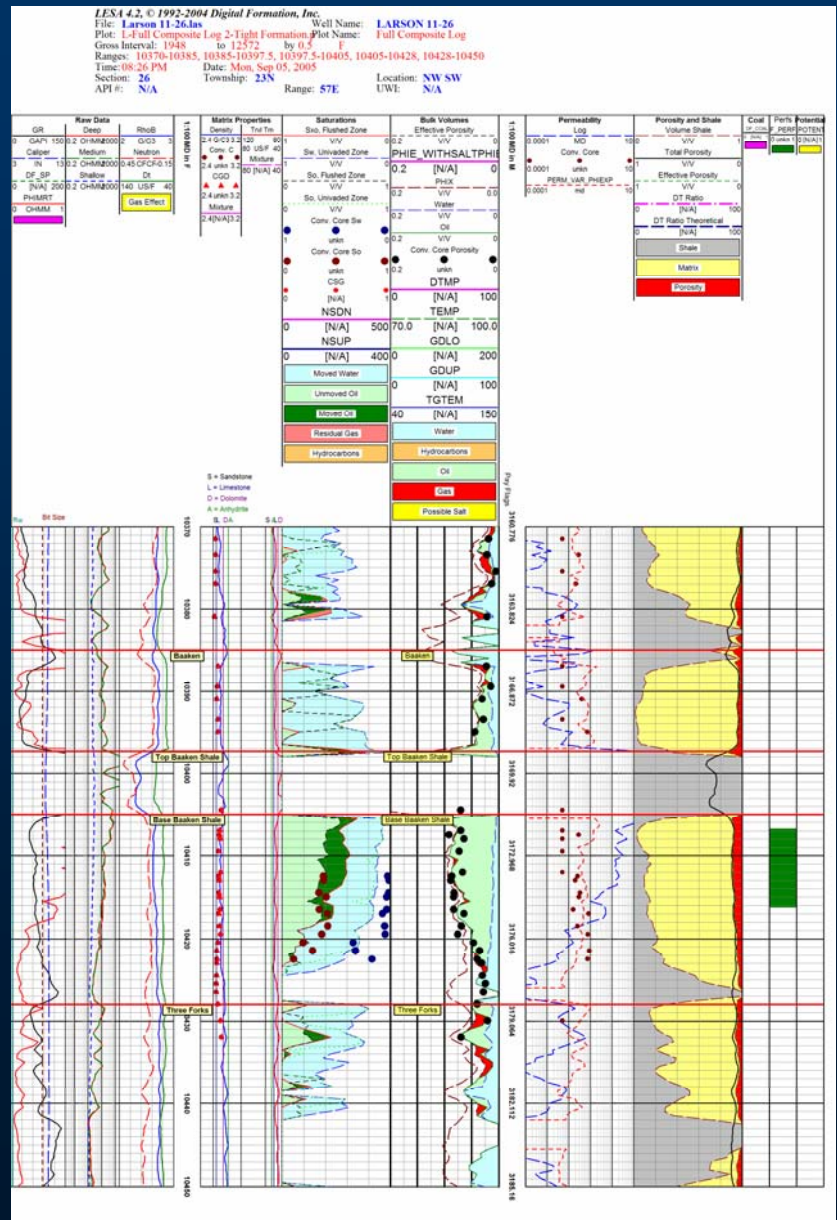


Pickett Plot

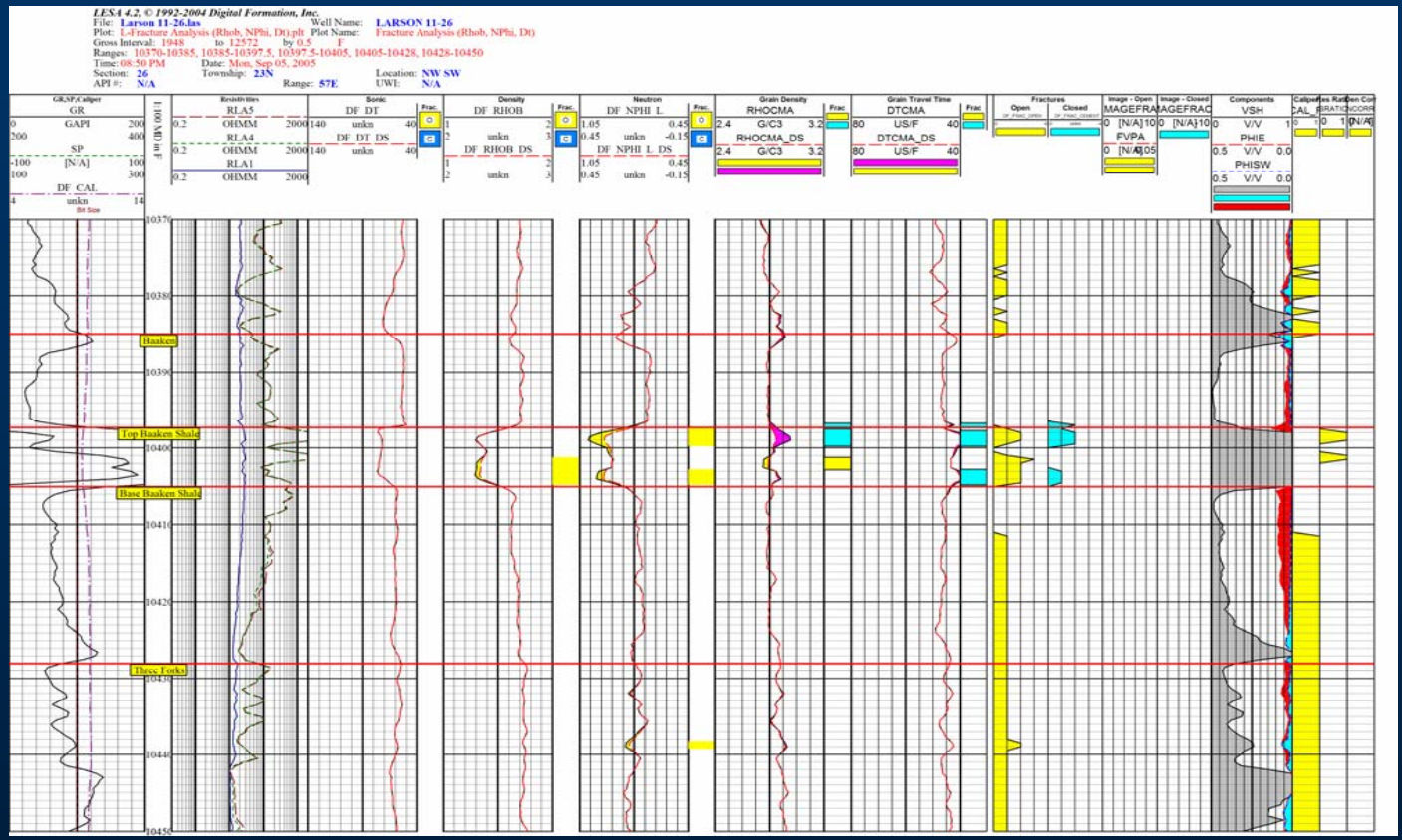


Basic Petrophysical Interpretation and Core/Log Comparisons

- Good correlation between core and log porosity and grain density
- Good correlation between log “unmoved oil” and core oil saturation
- Core water saturation appears to be anomalously low



Fracture Analysis



- Based on abnormal rates of change of raw porosity log curves, and out of gauge hole
- Bakken shale appears to contain both open and closed fractures
- The only fracture indicator in the Bakken dolomite is out of gauge hole

Permeability Modeling

- Timur transform is:

$$k = \frac{62500 \times \phi_e^{\,6}}{S_{wi}^{\,2}}$$

And is a very poor predictor of permeability

$$k = \frac{62500 \times \phi_e^{\,VariableExponent}}{S_{wi}^{\,2}}$$

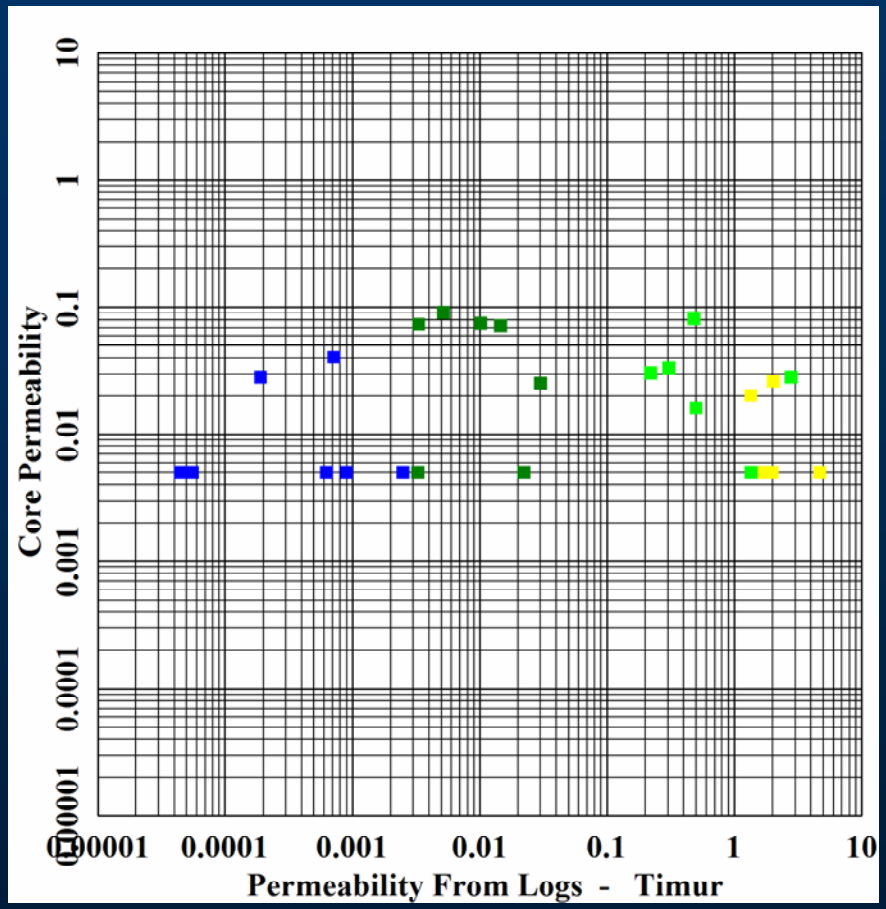
- Timur Variable Exponent transform is:

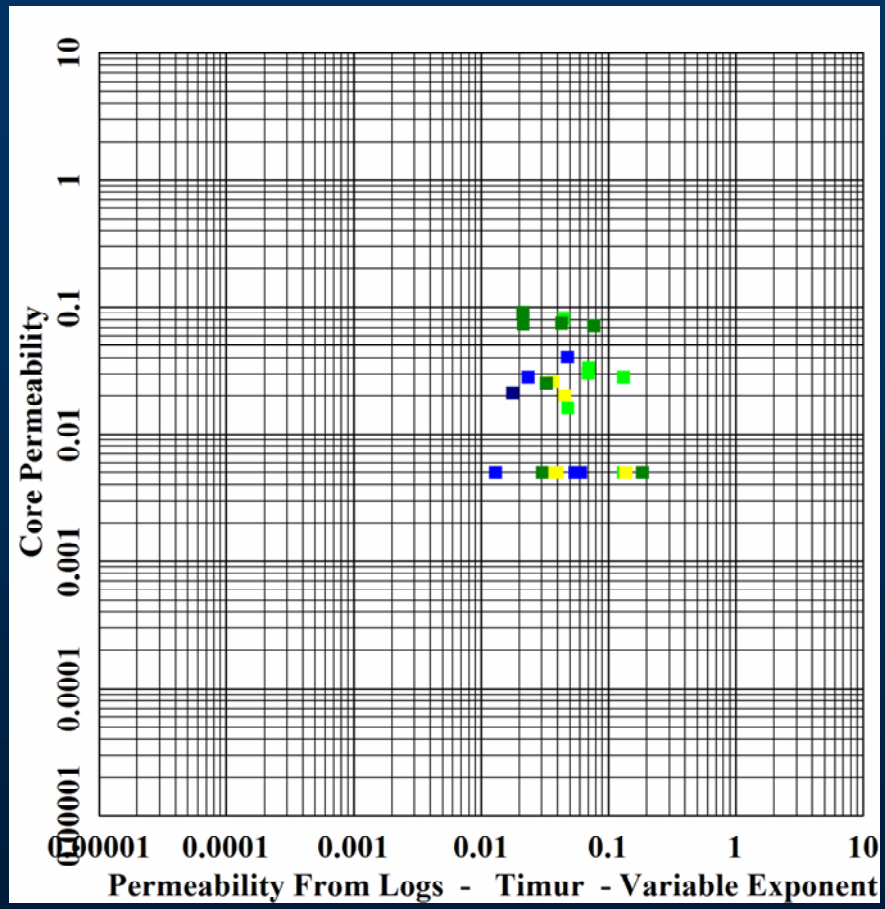
$$k = \frac{62500 \times \phi_e^{\,VariableExponent}}{S_{wi}^{\,2}}$$

Variable Exponent	Porosity	Exponent
	0.001	3
	0.22	15

Correlation is tighter, but still not very good

Permeability Modeling





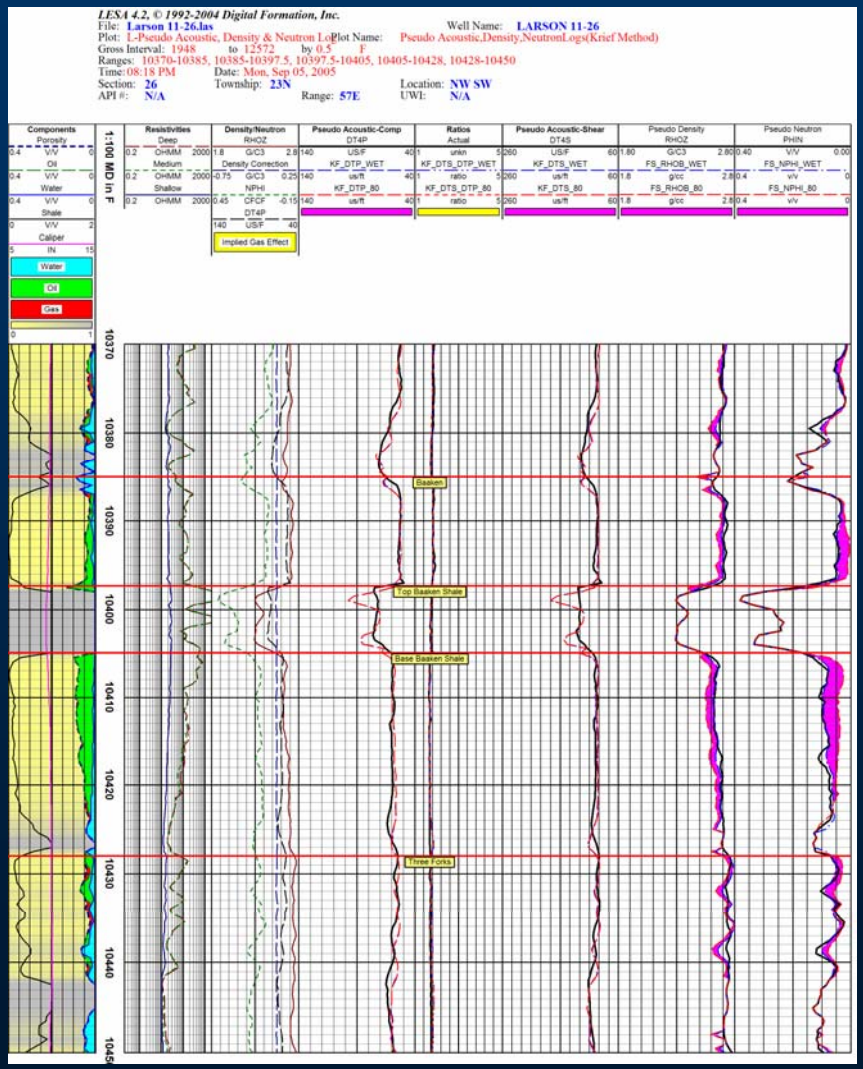
Porosity

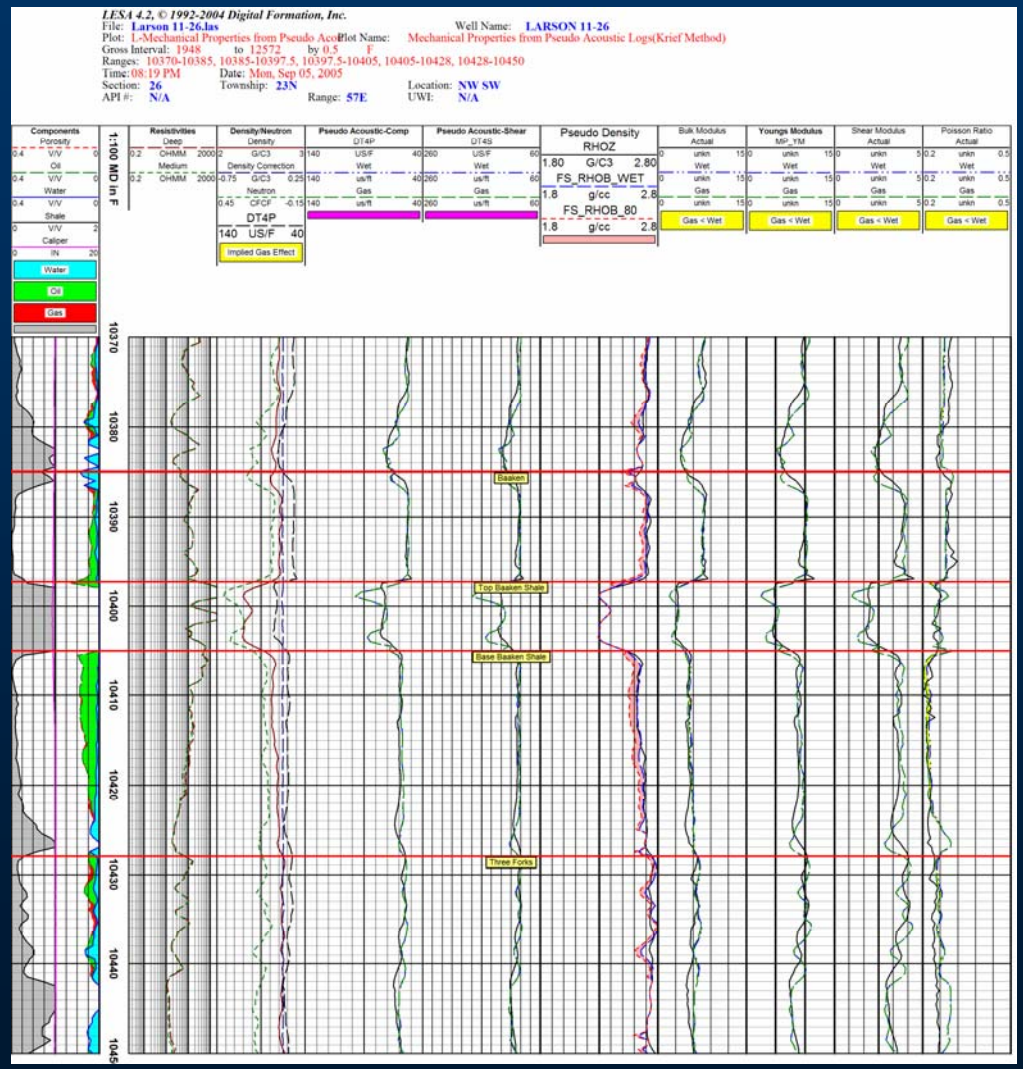
Dark Blue	*0 - 2%*	*Light Green*	*6% - 8%*
Light Blue	*2% - 4%*	*Yellow*	*8% - 10%*
Dark Green	*4% - 6$*		

Pseudo Logs and Mechanical Properties

- Pseudo logs are derived from a rock physics model using the geophysical Krief equation
- Good reconstruction of all porosity logs indicates data set has very good integrity
- Mechanical properties, derived from pseudo logs agree well with those calculated from measured logs
- Significant contrast between the Bakken shale and carbonates both above and below
- Contrast between the Bakken carbonates and the Three Forks carbonates is much more subtle

Pseudo Logs and Mechanical Properties

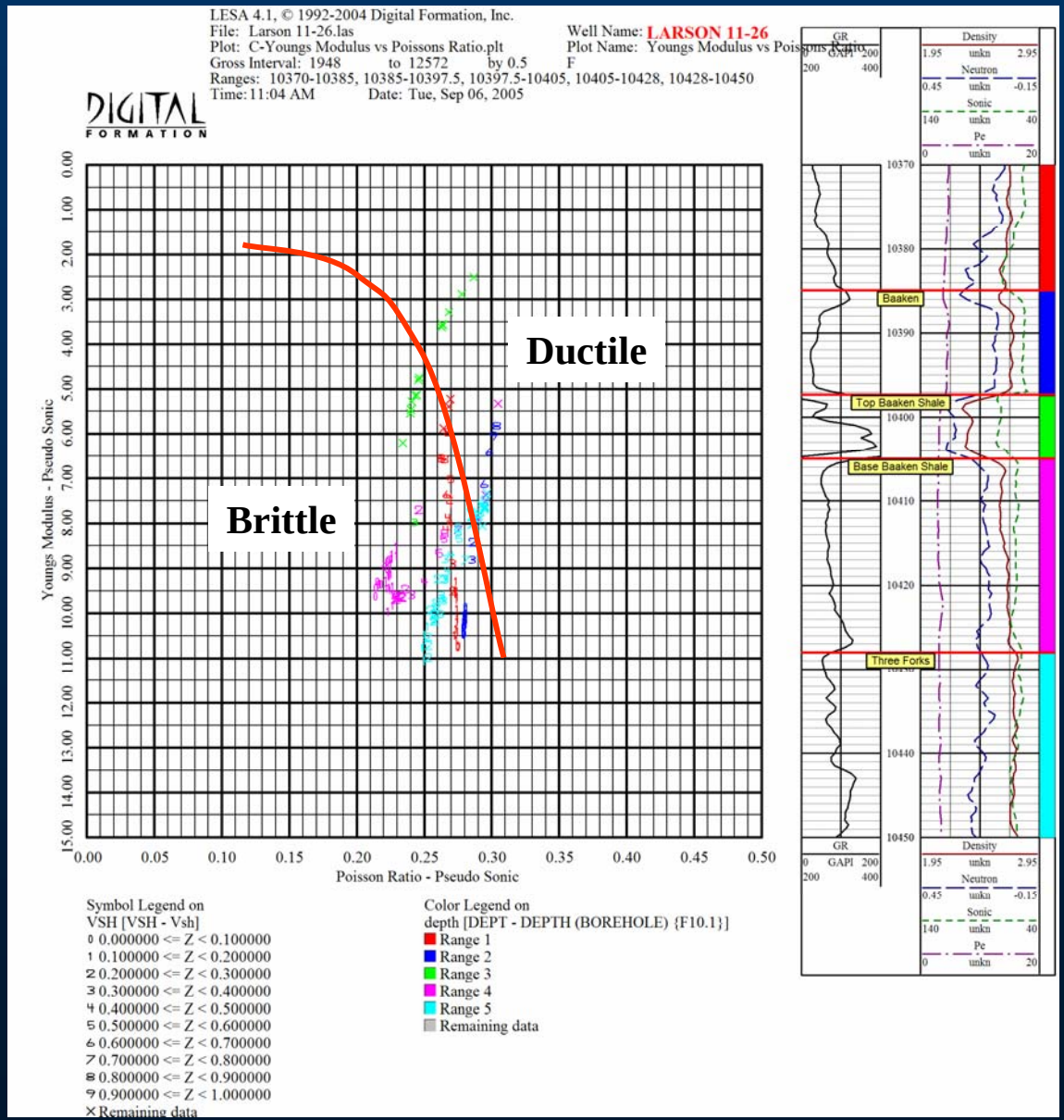




Comparison of Mechanical Properties

- Shows that part of the Bakken Shale and the Three Forks, are ductile, and the remainder of the sequence is brittle

Comparison of Mechanical Properties



Total Organic Carbon

- Technique is based on identifying shale intervals to have very low TOC, and to compare resistivity of the organic thick shales with these low TOC Shales (ΔR techniques) See AAPG December 1990 p. 1777 – 1794
- Bakken shale shows a TOC of about 10%, assuming LOM = 11 i.e. good source rock potential

Total Organic Carbon

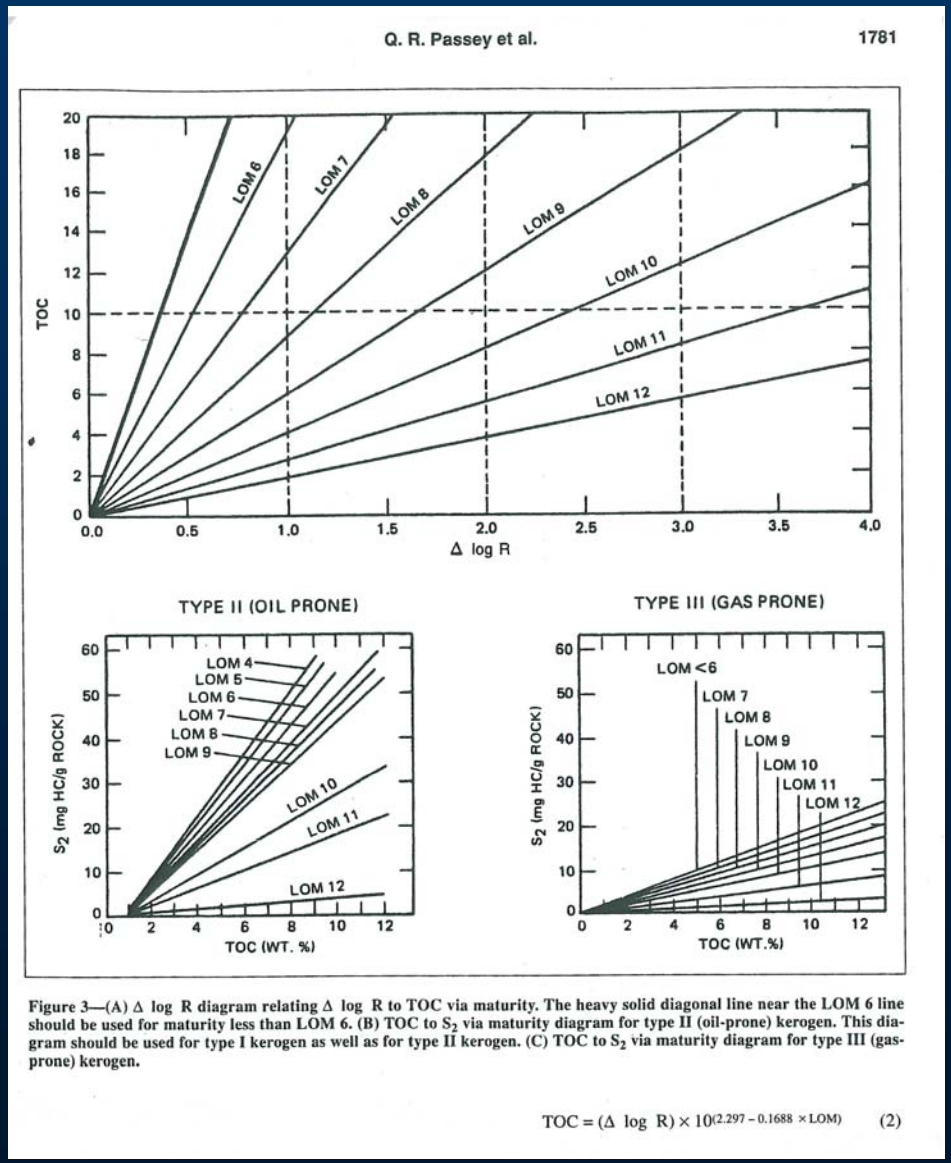
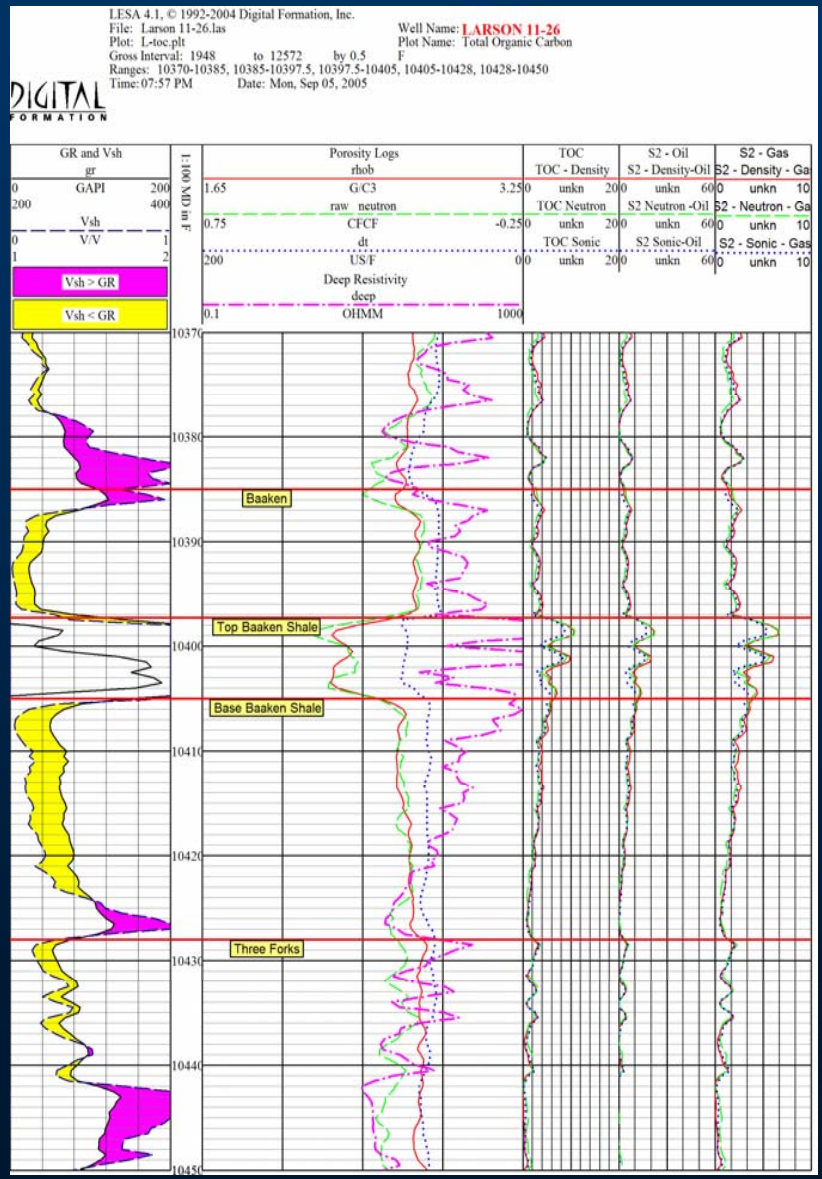


Figure 3—(A) Δ log R diagram relating Δ log R to TOC via maturity. The heavy solid diagonal line near the LOM 6 line should be used for maturity less than LOM 6. (B) TOC to S_2 via maturity diagram for type II (oil-prone) kerogen. This diagram should be used for type I kerogen as well as for type II kerogen. (C) TOC to S_2 via maturity diagram for type III (gas-prone) kerogen.

$$TOC = (\Delta \log R) \times 10^{(2.297 - 0.1688 \times LOM)} \quad (2)$$



Conclusions

- Petrophysical modeling gives good estimates of porosity, fluid substitution, and grain density when compared with core measured values
- Permeability of these Bakken dolomites are extremely low (less than 0.1 md). Petrophysical models to predict permeability from other measurements (porosity, irreducible water saturation) are not very satisfactory
- Mechanical properties of the producing Bakken interval are quite different from the overlying Bakken shale, and subtly different from the underlying Three Forks
- TOC values of the Bakken shale are high (10%) indicating good source rock potential