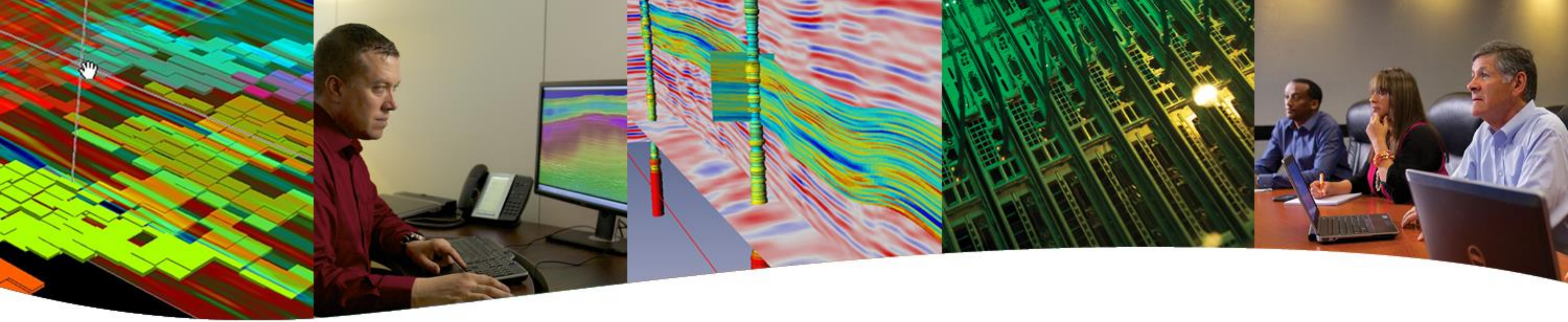


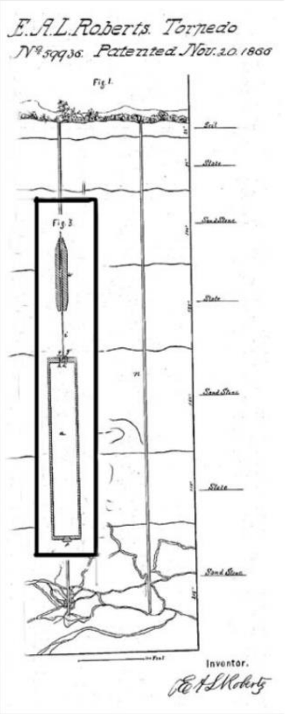
Fracture Simulation Parameters

Addressing the Needs of Completion Engineers—A Petrophysical Perspective

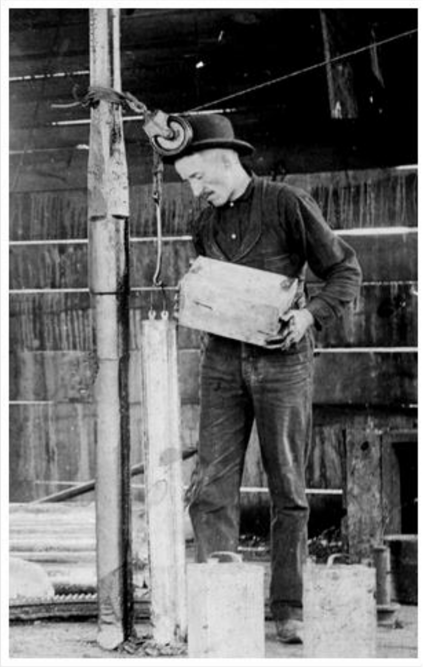
Fred Jenson, Petrophysics and Geomechanics Expert

CGG GeoSoftware

History of Fracture Simulation



Torpedoes filled with gunpowder (later nitroglycerin) were lowered into wells and ignited by a weight dropped along a suspension wire onto a percussion cap.



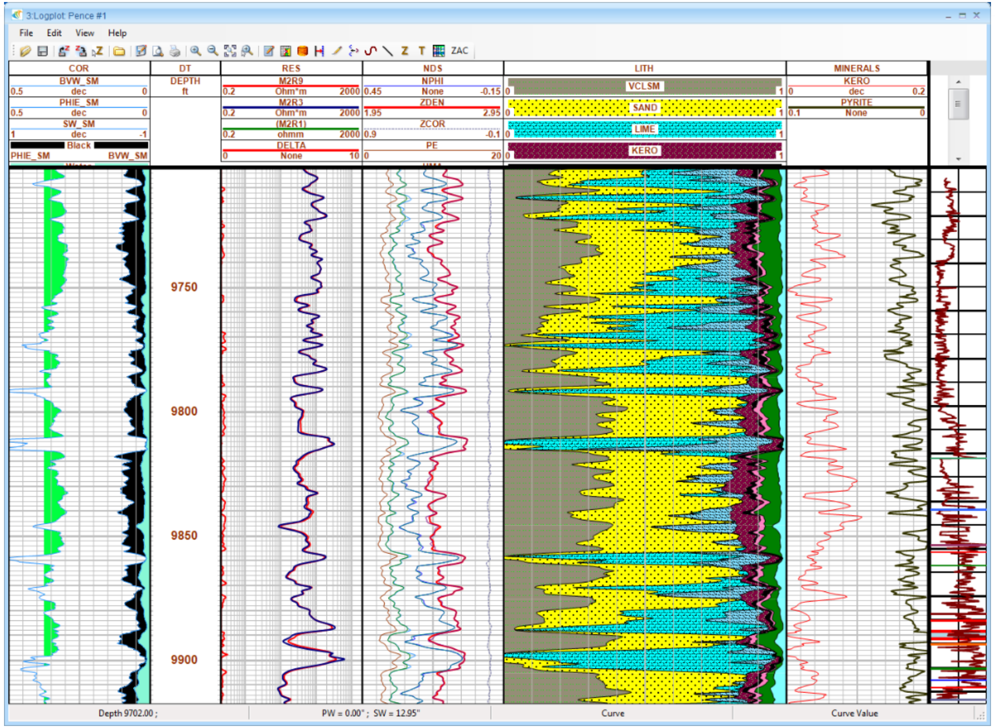
Pouring nitroglycerin was risky enough in late 19th century oilfields. Doing it for an illegal well "shooting" led to the term "moonlighting."

Photographs comparing of the first hydraulic fracturing operation in 1947 with a modern shale gas frac-pad

The Elements of Frac Design

- Detailed petrophysical analysis of zone of interest
- Computation or estimation of elastic properties
- Determination of rock and fluid properties
- Interval averaging of log values for input into simulator
- Parameter testing to insure rock and fluid properties match well test results
- Transfer of rock and fluid properties into simulator and run simulation

Petrophysical Evaluation



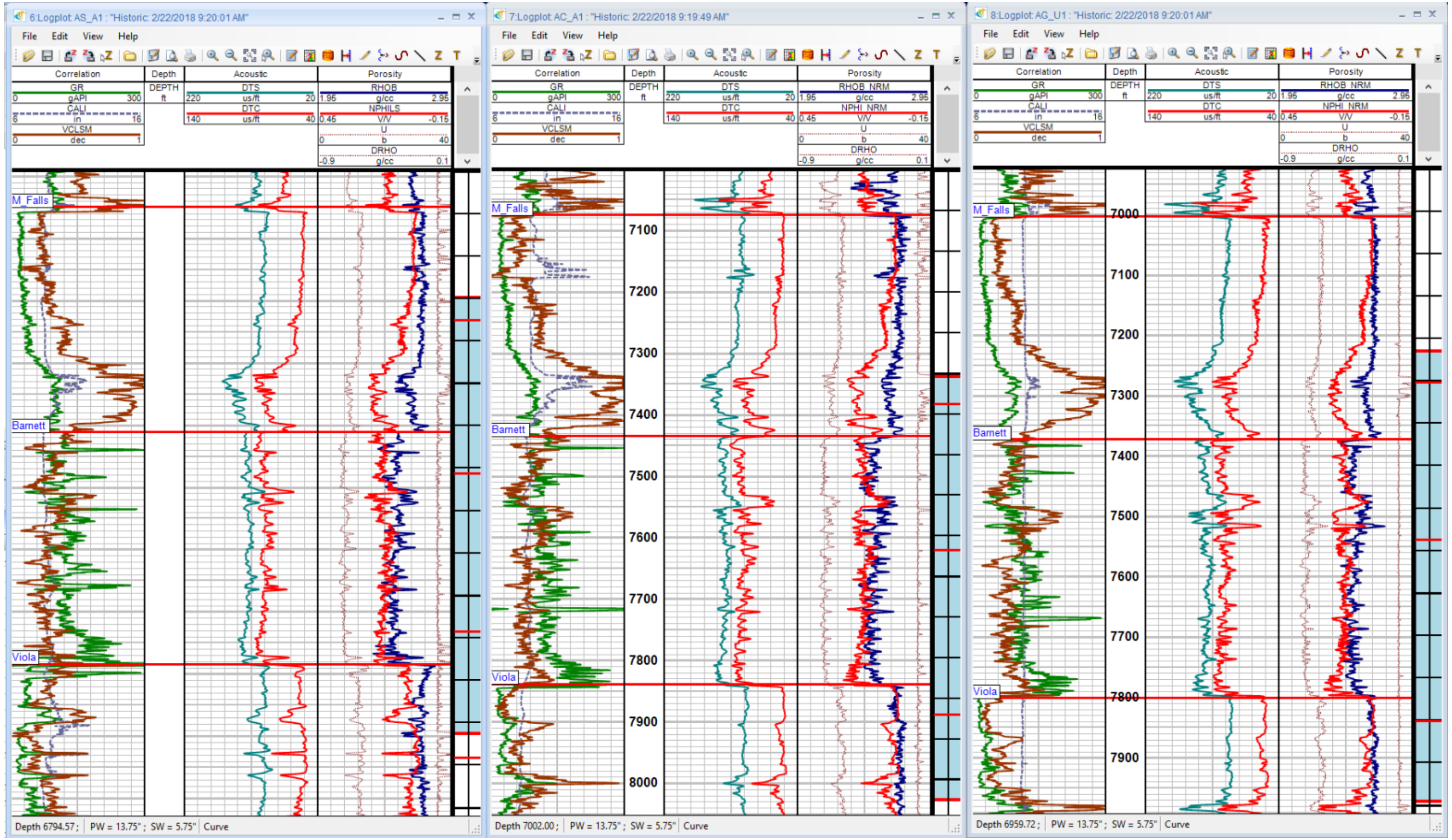
Parameters of Interest

- Water Saturation
- Porosity
- Permeability
- Clay Volume
- Lithology

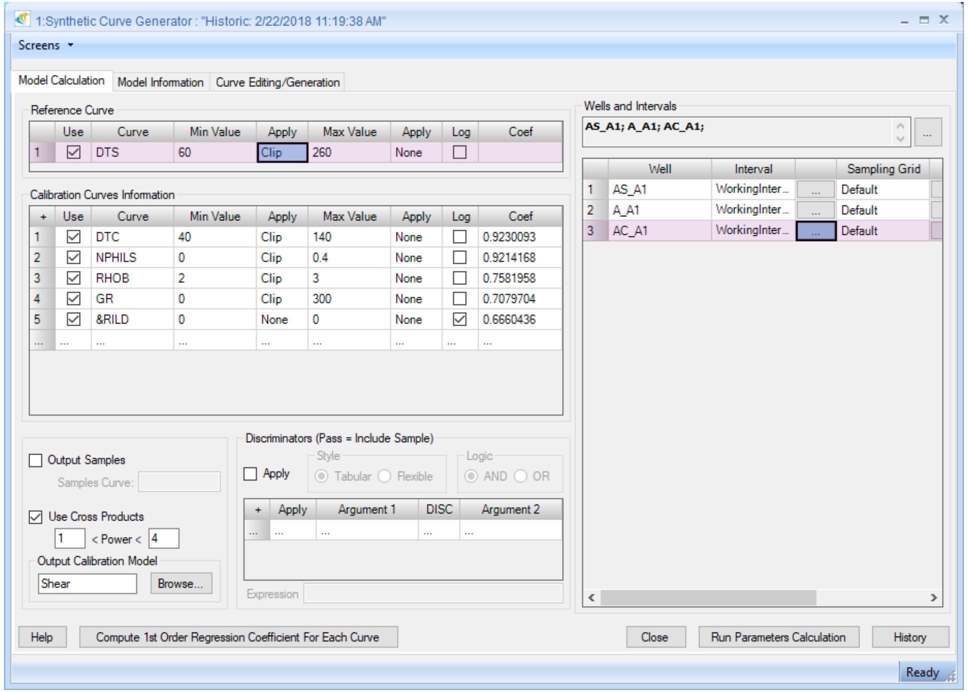
Determining Elastic Properties (wells with log data)

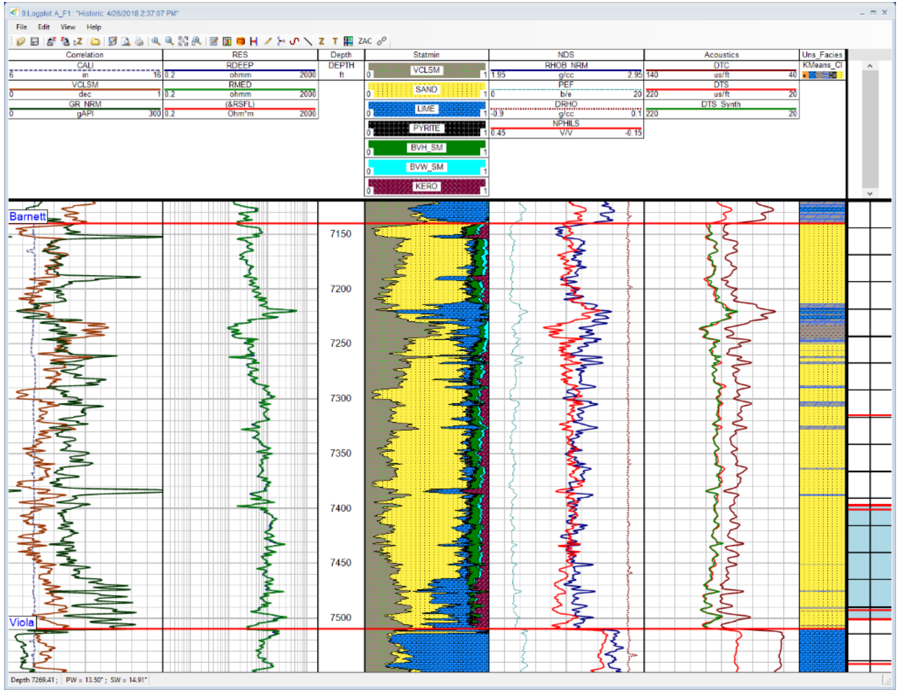
- Deterministic computations where compressional sonic, shear sonic, and density curve are measured over the zone of interest
- Computation of synthetic acoustics when DTS (shear acoustic log) and/or DTC (compressional acoustic log) are not acquired
  - Estimated from other logs in the well (RHOB, NPHI, DTC, GR, etc.) (Synthetic Curve Generation)
  - Generated using Deep Learning Models with Python Extensions (also using other curves)
  - Determined from a detailed rock physics model constructed over zone of interest
- Empirical equations for estimation of elastic properties when minimal logs are present

Barnett Wells with Measured DTC and DTS

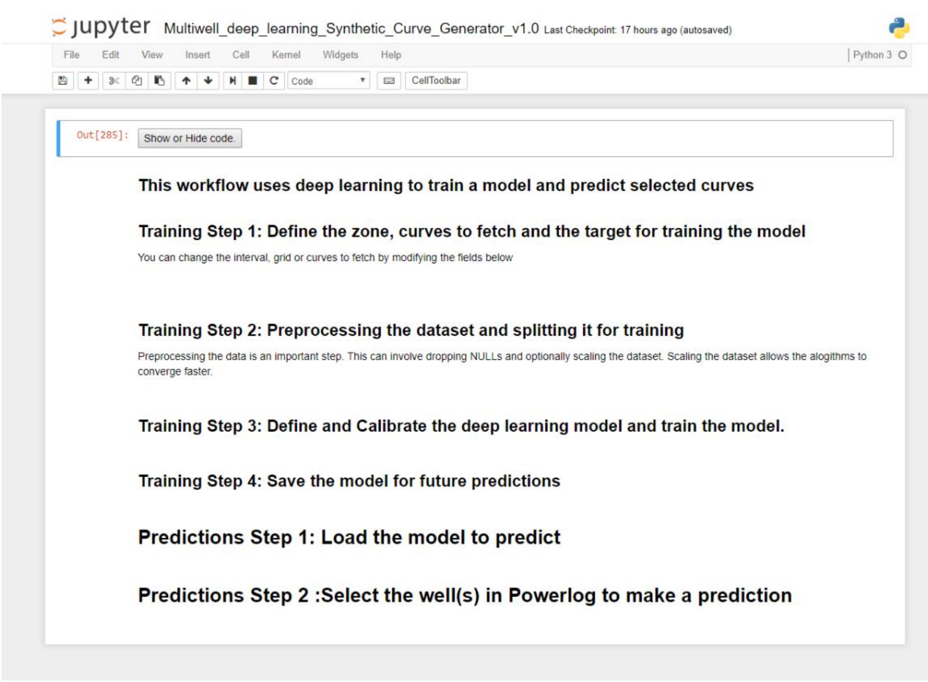


Generate Synthetic DTS from Nearby Wells





Deep Learning Model for Synthetic DTS



jupyter Multiwell_deep_learning_Synthetic_Curve_Generator_v1.0 Last Checkpoint: 17 hours ago (autosaved)

File Edit View Insert Cell Kernel Widgets Help | Python 3

Out[285]: Show or Hide code.

This workflow uses deep learning to train a model and predict selected curves

Training Step 1: Define the zone, curves to fetch and the target for training the model

You can change the interval, grid or curves to fetch by modifying the fields below

Training Step 2: Preprocessing the dataset and splitting it for training

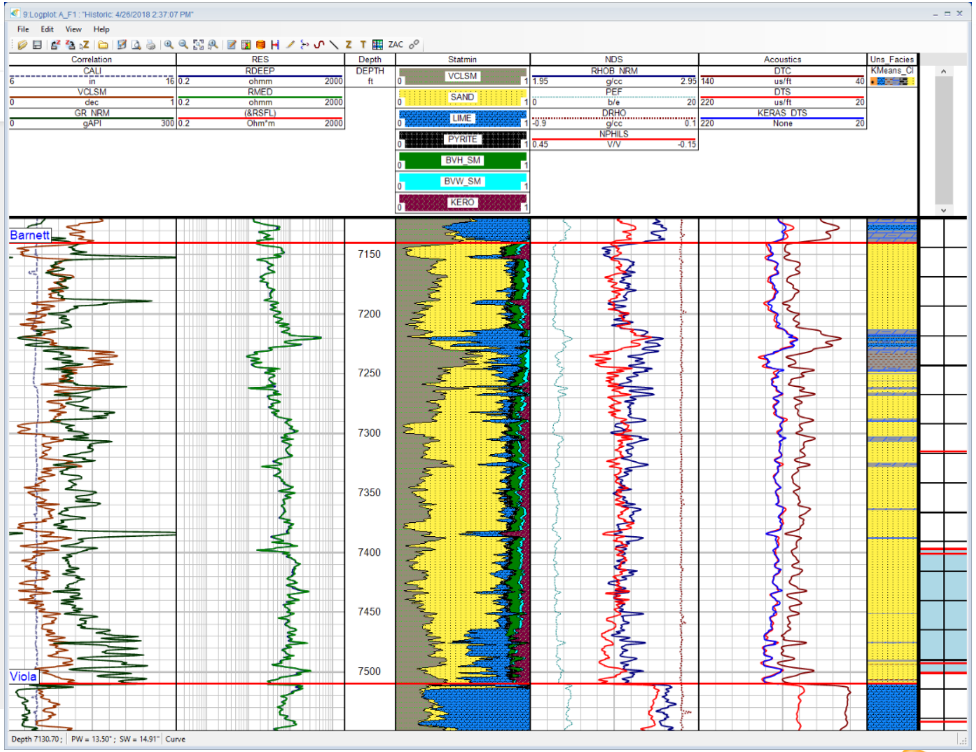
Preprocessing the data is an important step. This can involve dropping NULLs and optionally scaling the dataset. Scaling the dataset allows the alogithms to converge faster.

Training Step 3: Define and Calibrate the deep learning model and train the model.

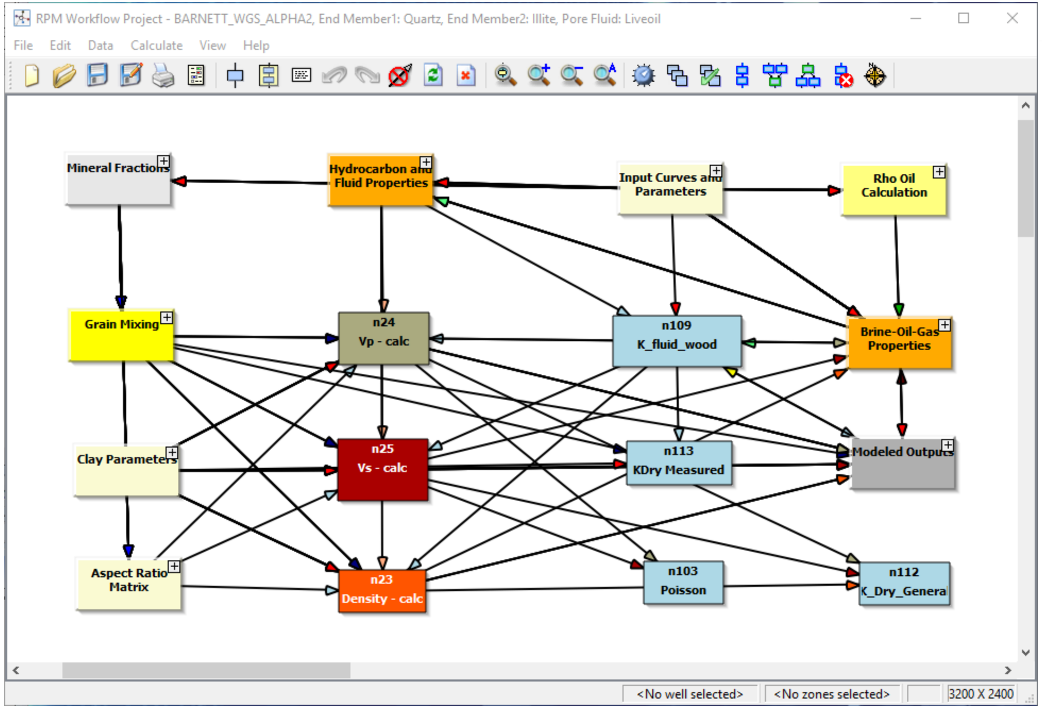
Training Step 4: Save the model for future predictions

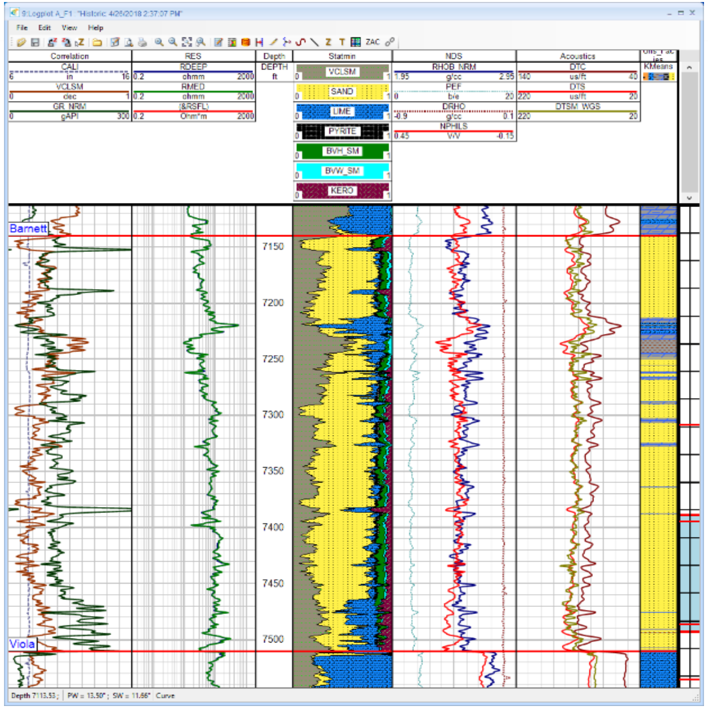
Predictions Step 1: Load the model to predict

Predictions Step 2 :Select the well(s) in Powerlog to make a prediction



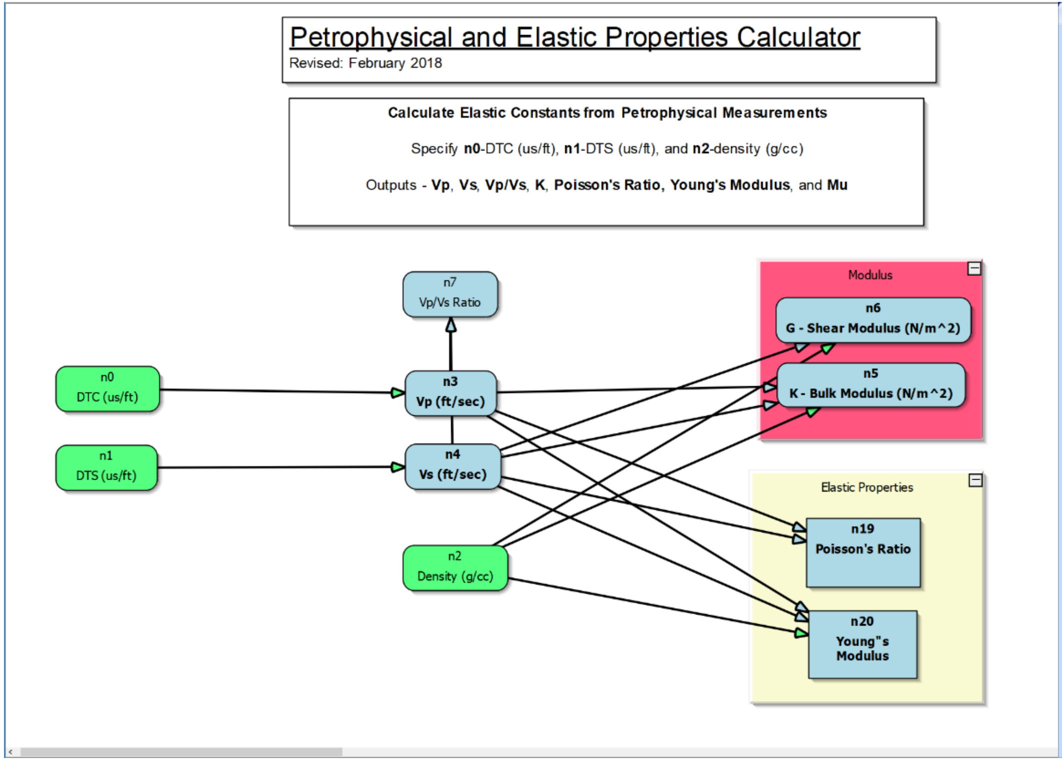
Rock Physics Models for Elastic Properties

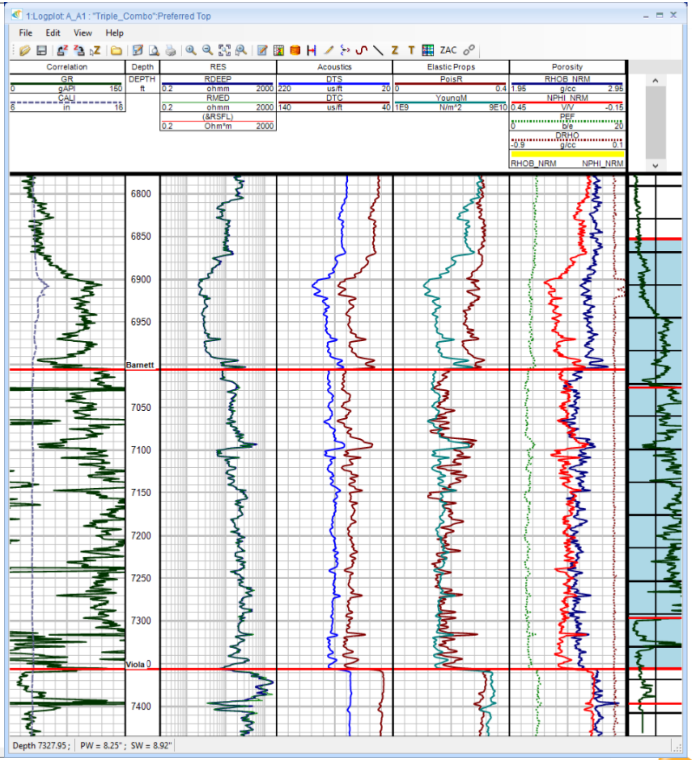




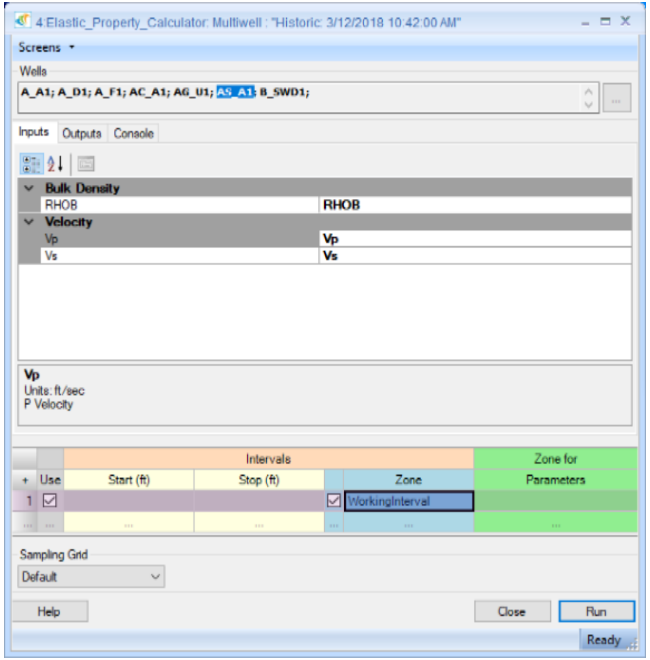
Required inputs for rock physics modeling include lithology, porosity, water saturation, pressure, temperature, and fluid properties. The aspect ratio is estimated based on lithology.

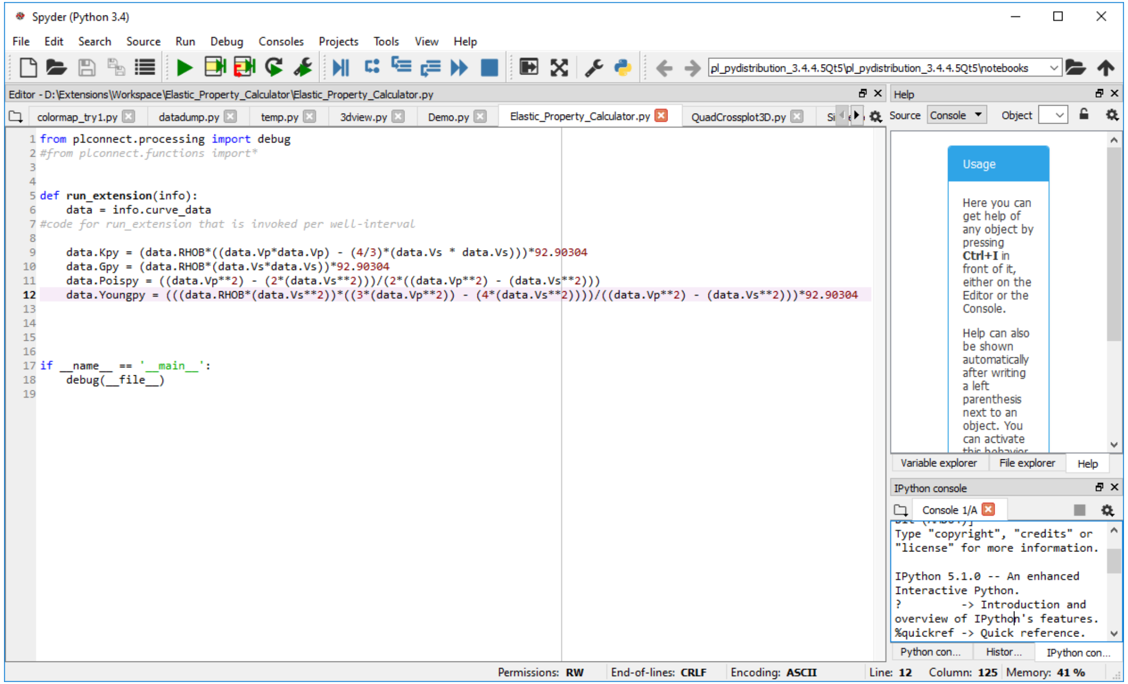
Deterministic Elastic Properties (Rock Physics Application)





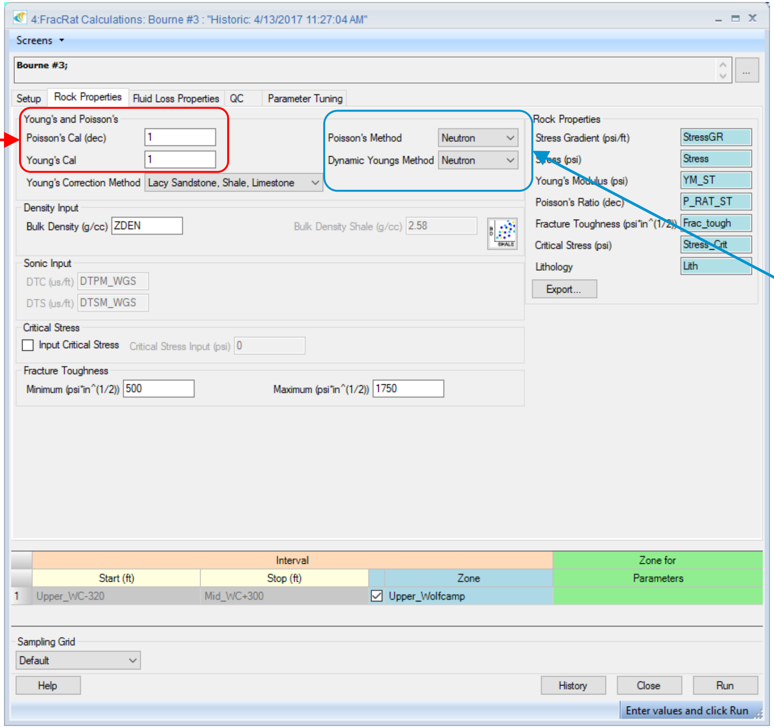
Computing Elastic Properties (Python Script)





Empirical Estimation of Elastic Properties

Multiplier to match known values when available

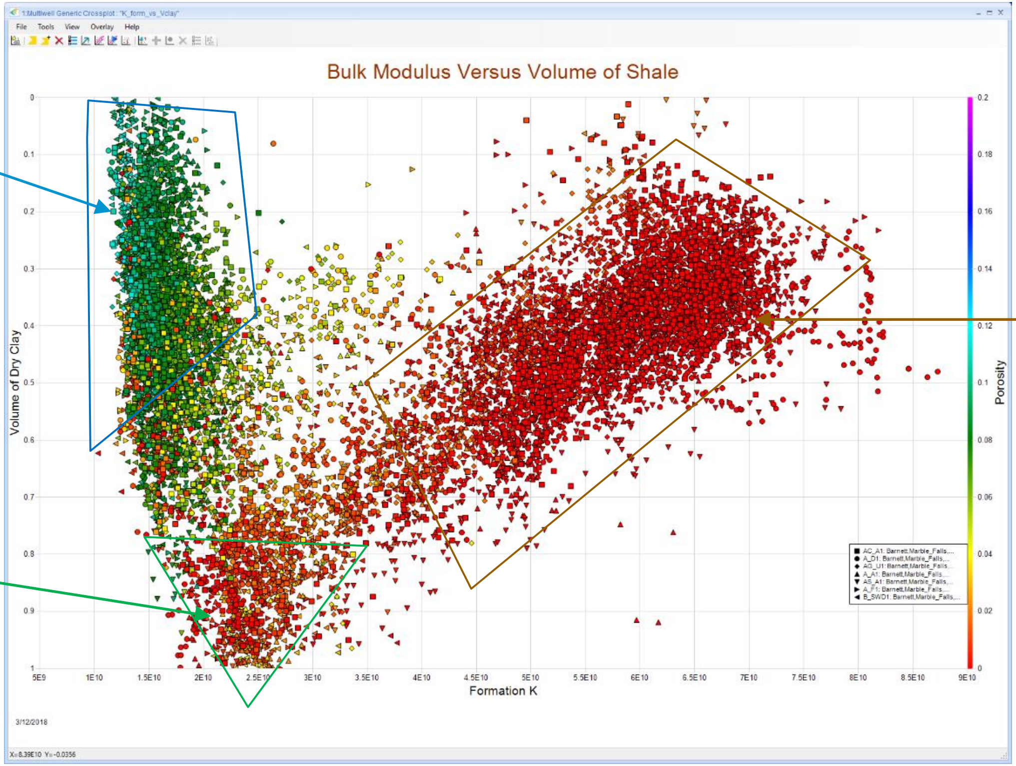


- Empirical options for estimation of Poisson's Ratio and Young's Modulus
  - De-Hua Han
  - Castagna
  - Neutron

Bulk Moduli versus Vshale (Color Scale is Porosity)

Barnett Shale

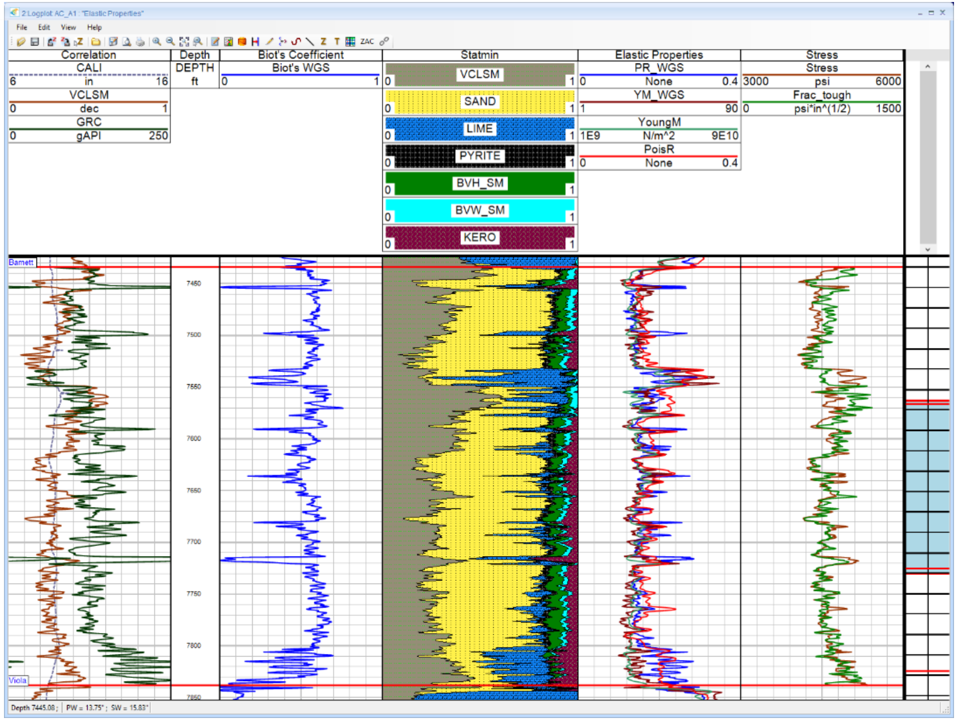
Area used to estimate bulk moduli of clay



Marble Falls and Viola Limestones

Biot's Coefficient (Required Input for Some Simulation Packages)

The full rock physics modeling for elastic properties enables estimated determination of Biot's Coefficient along with the Poisson's Ratio and Young's Moduli. The Stress computations were performed in FracRAT.

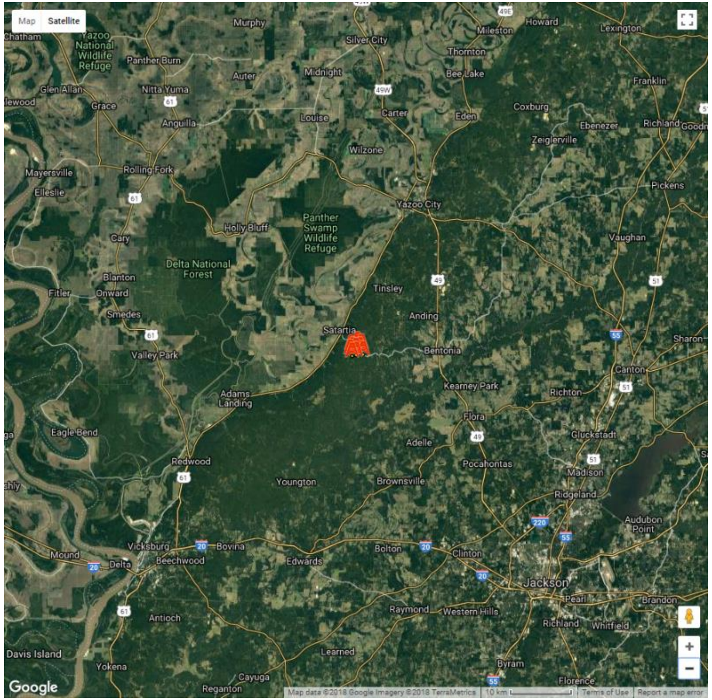


Biot's = 1 – Kdry/Ko   where Ko is KVRH, the bulk moduli of the rock framework (Mavko, Mukerji, and Dvorkin, The Rock Physics Handbook, 1998)

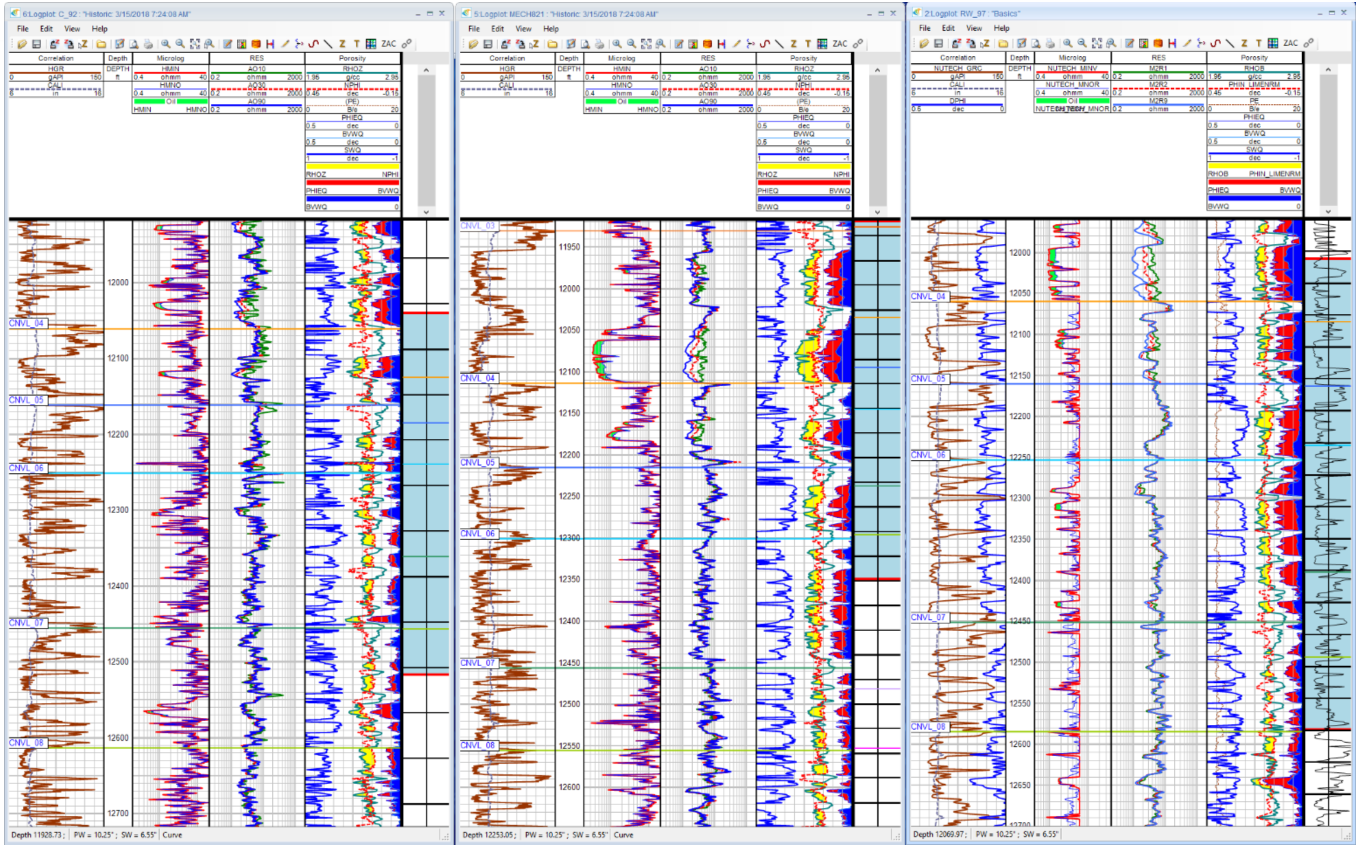
Frac Preparation Examples

- Mississippi tight gas sand example
  - Cotton Valley formation, upper Jurassic age
  - Low porosity clastic sandstones (very common case globally)
  - Partially depleted after initial completion including frac
  - Post frac tracer survey very useful
  - Planned recompletion, never executed
- West Texas Unconventional example
  - Spraberry Wolfcamp formations, Permian age
  - High Kerogen content
  - Uranium salts associated with high Kerogen volume rocks
  - Actual frac design did not use analysis results

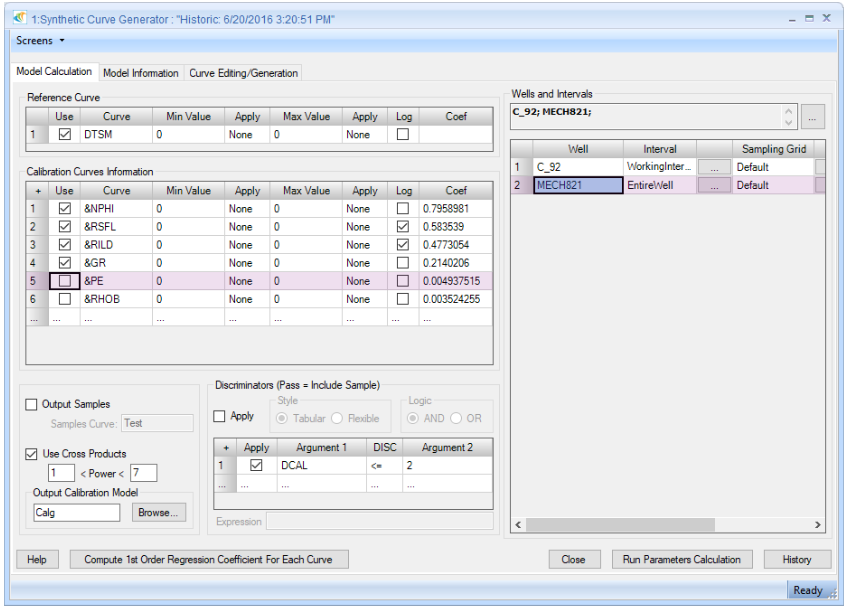
Mechanicsburg Field, Mississippi

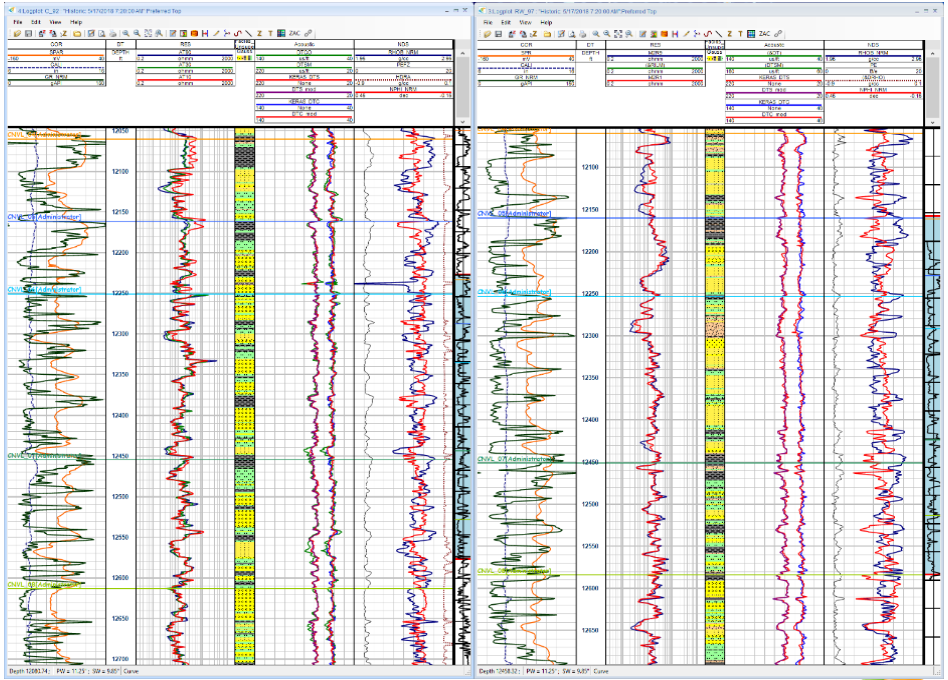


Mississippi Tight Gas Sands

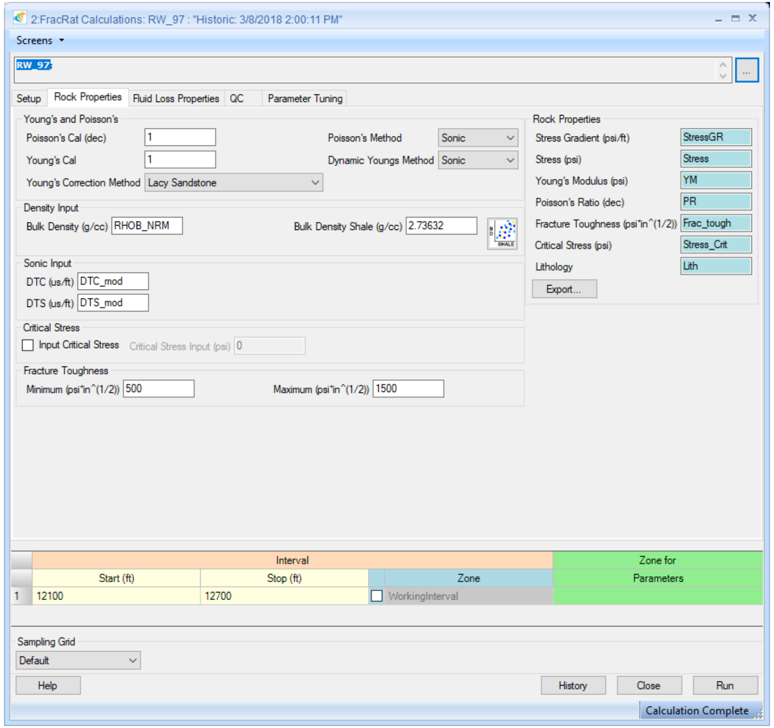


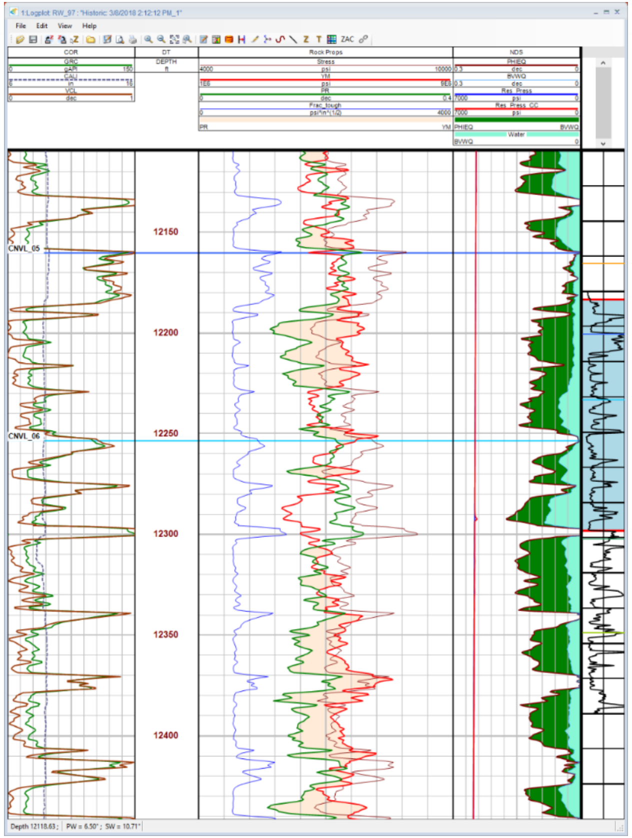
Generate Modeled DTC and DTS



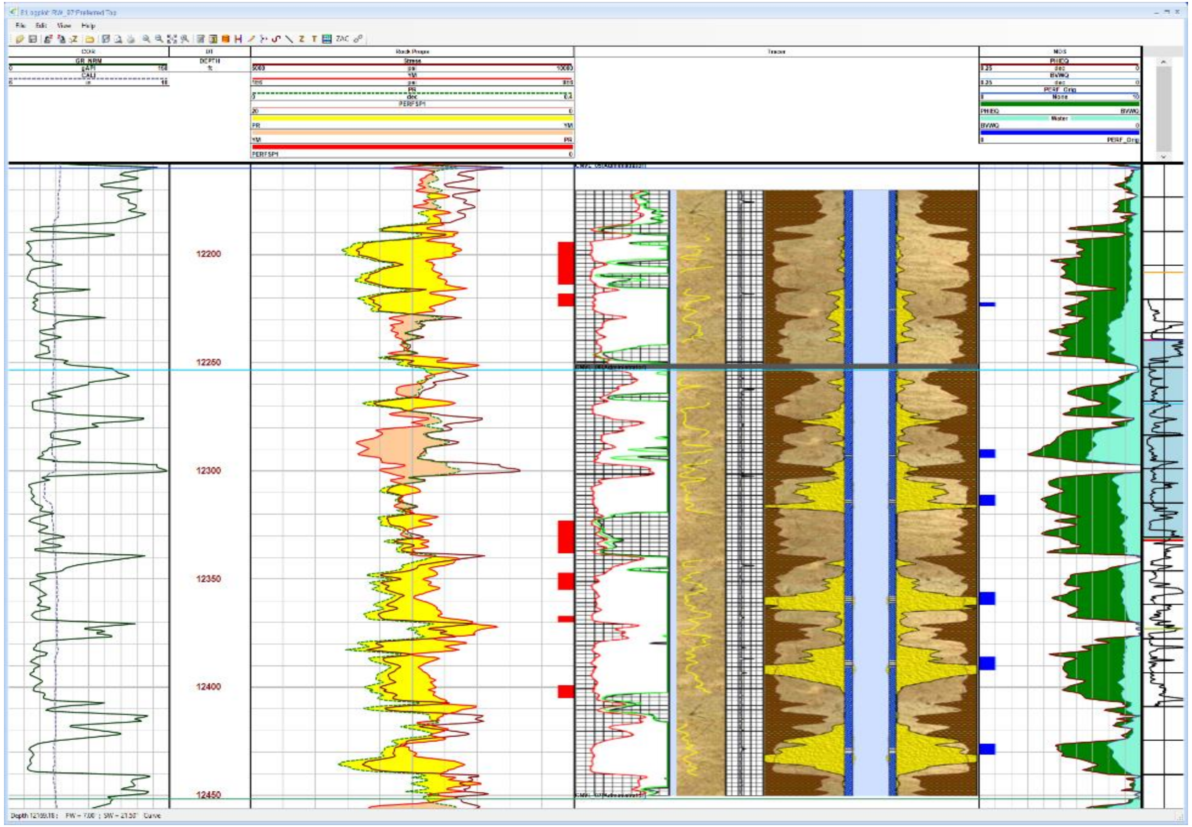


Calculate Rock and Fluid Properties





Post Frac Tracer Surveys

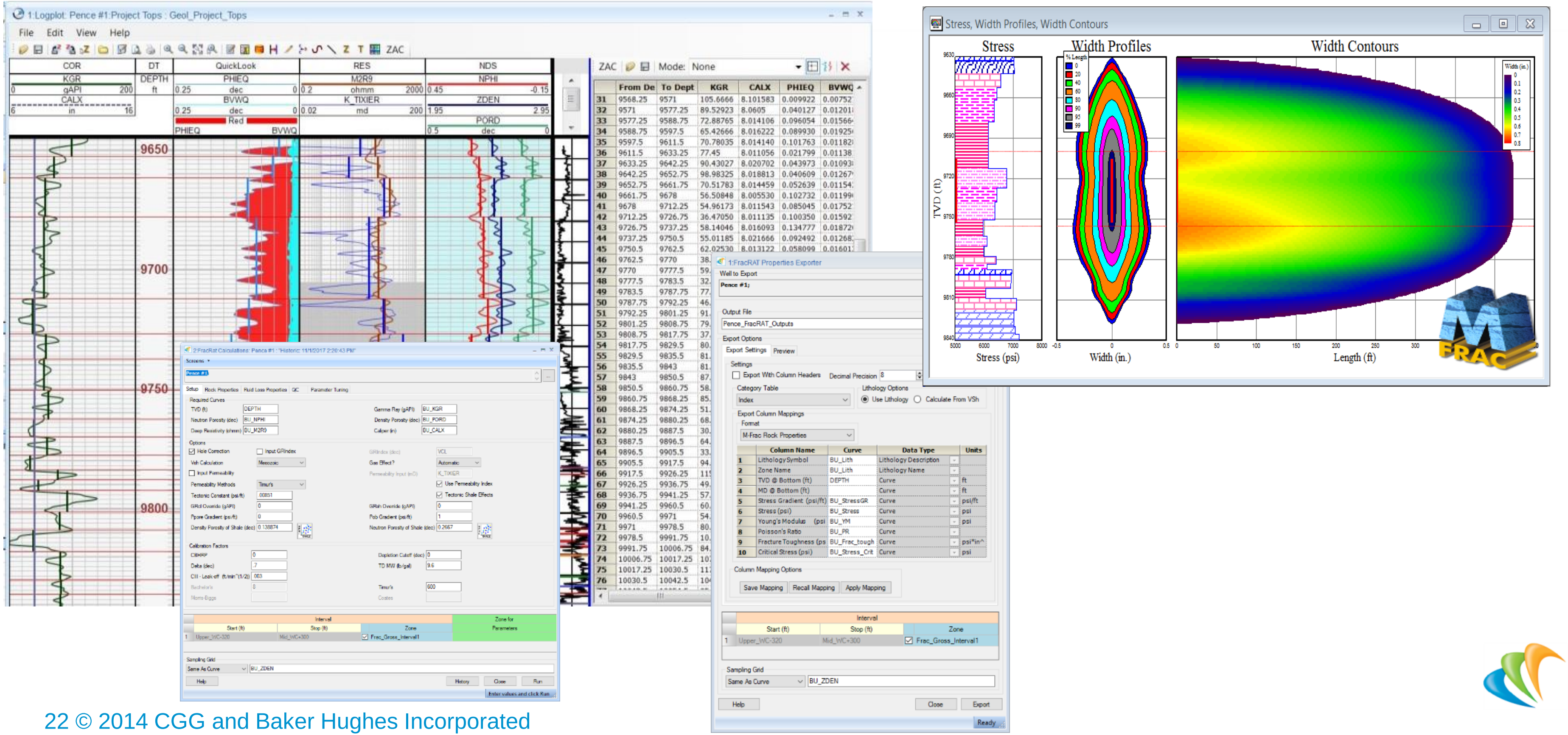


Spraberry Wolfcamp Unconventional Example

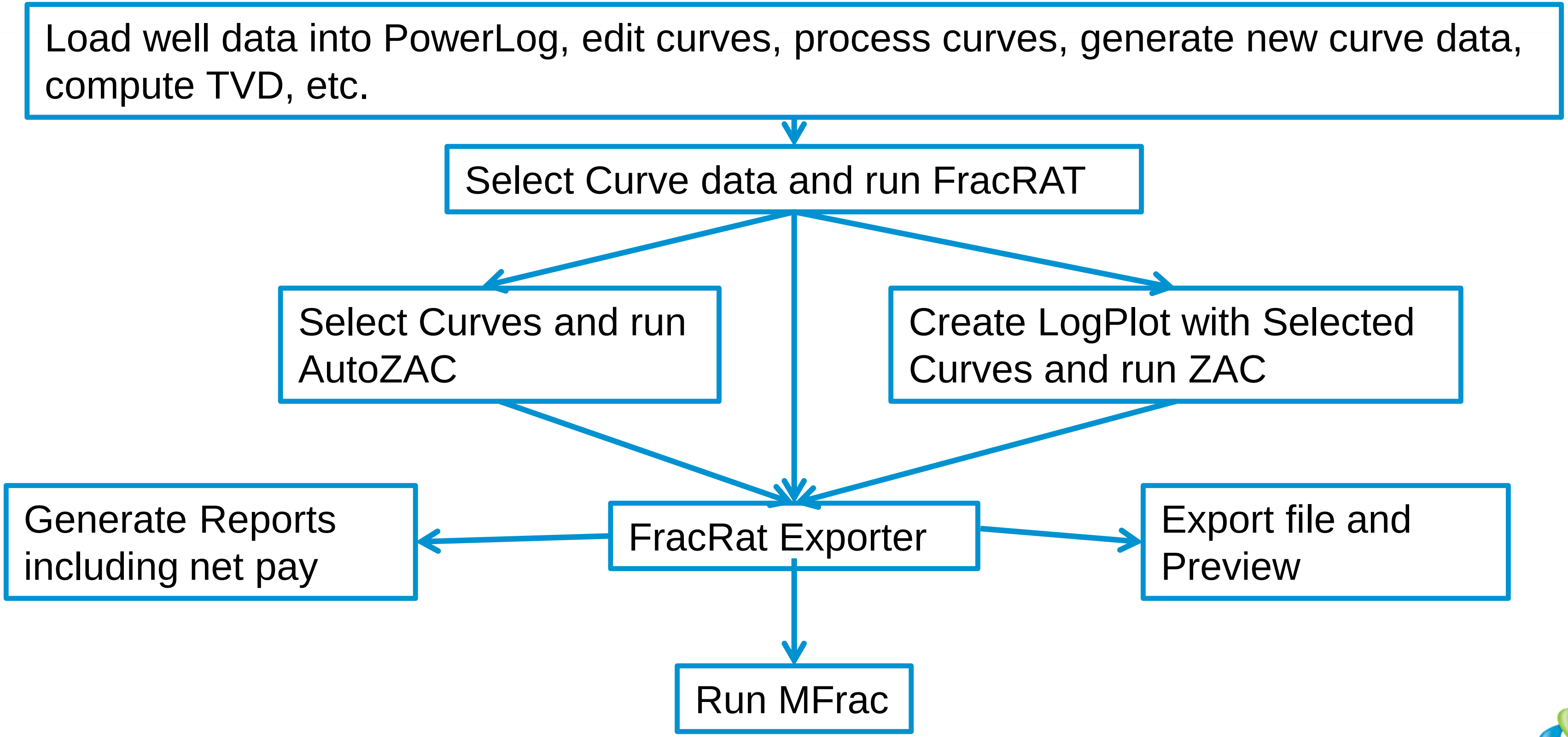
The next section deals with design of a frac in an unconventional reservoir with minimal log suite. No advanced acoustic data is available in any of these wells. There is no cartographic data associated with these wells, so no Google Maps can be displayed.

FracRAT (a module of PowerLog) is used to generate the rock and fluid properties for input into the fracture simulation software package. In this case we are using Mfrac for simulation.

Elements of PowerLog Frac - MFrac Workflow

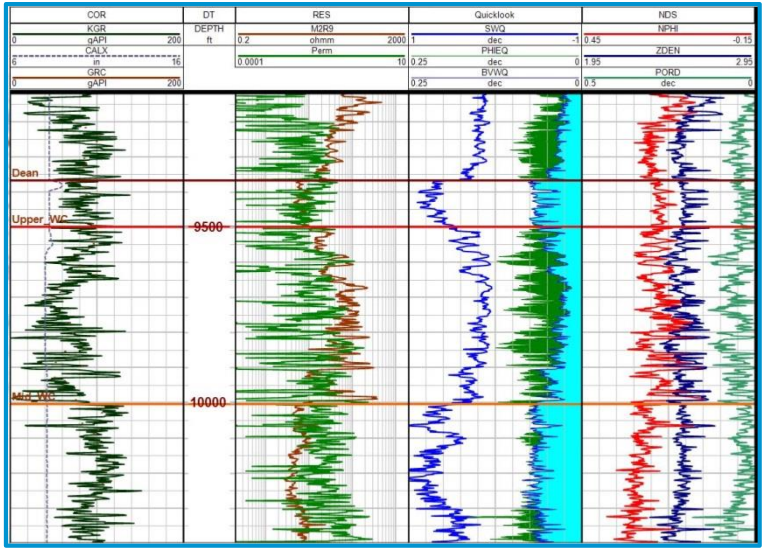


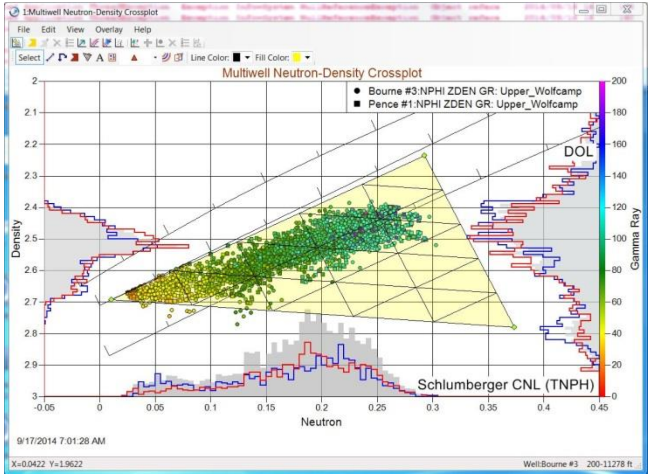
PowerLogFrac Workflow



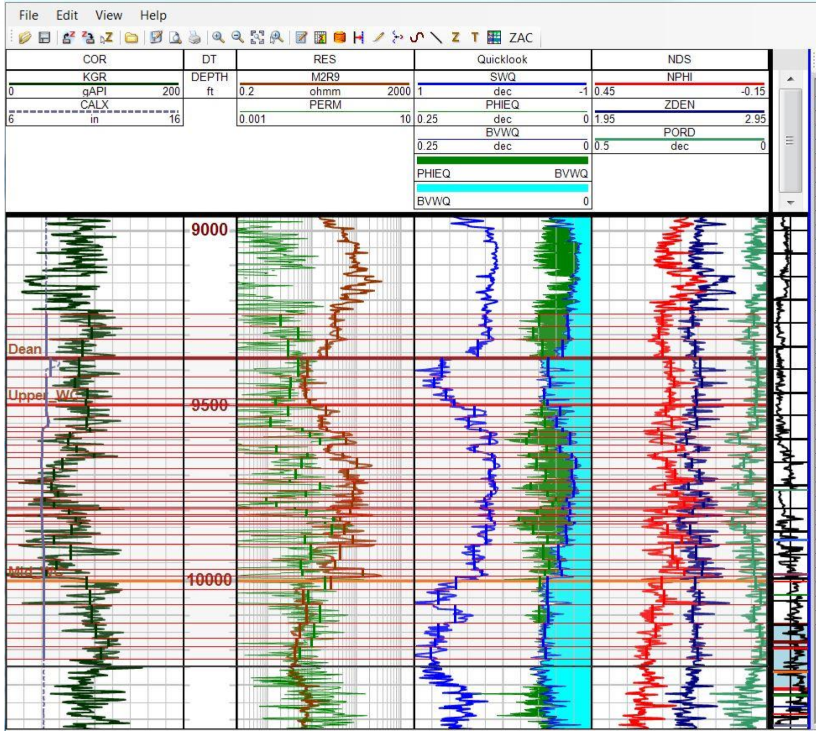
PowerLog: Petrophysical package

Load well data, edit curves, process curves, generate new curve data, compute TVD, etc.





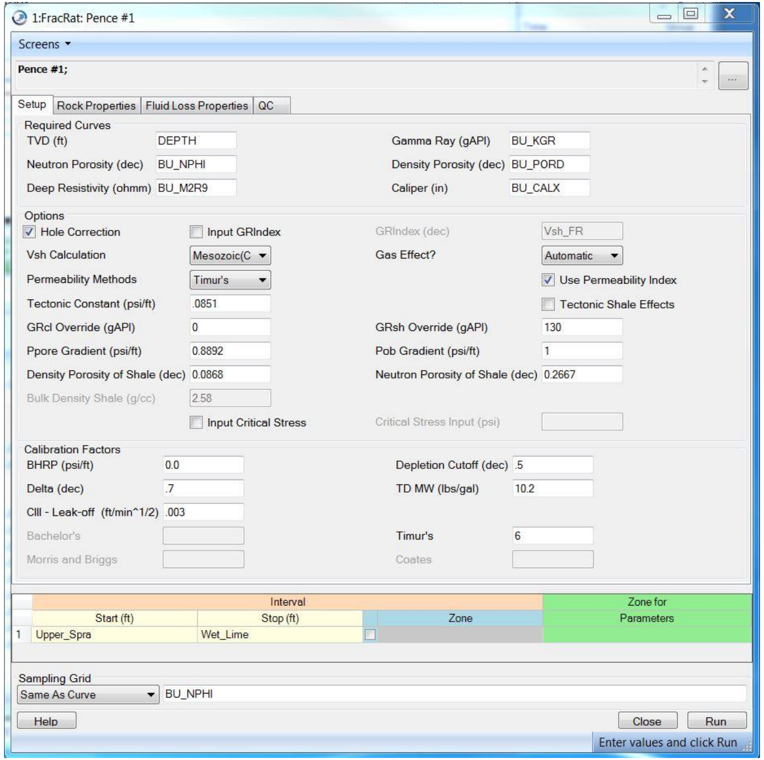
ZAC (Zone Average Calculator)



Mode: Add Zones | Cursor Tracking | Create Curves | Exit

	From De	To Dept	KGR	CALX	M2R9	PERM	SWQ	PHIEQ	BVWQ	NPHI
1	9239.25	9275.5	93.59068	8.247123	32.56470	0.009732	0.195720	0.073574	0.033928	0.210113
2	9275.5	9312	96.24244	8.248163	37.27632	0.024564	0.163730	0.082723	0.032304	0.221085
3	9312	9361.5	85.73447	8.247256	21.24107	0.014508	0.285577	0.069657	0.040748	0.211266
4	9361.5	9417.75	81.89840	8.525778	7.917517	0.024323	0.689646	0.061834	0.061370	0.181482
5	9417.75	9449.25	78.03748	8.247440	6.969598	0.016698	0.776777	0.058335	0.058335	0.170242
6	9449.25	9481.25	91.45054	8.251279	7.036922	0.015643	0.645372	0.066958	0.066725	0.183926
7	9481.25	9500	89.44789	8.251802	9.085565	0.007378	0.551255	0.066522	0.062053	0.184581
8	9500	9532	92.35658	8.286891	20.52930	0.014314	0.319571	0.070262	0.044334	0.199944
9	9532	9564	90.38511	8.343077	16.63558	0.005662	0.382799	0.066324	0.049566	0.178889
10	9564	9575.5	94.25446	8.095808	21.67476	0.030110	0.258539	0.079051	0.041449	0.223977
11	9575.5	9591.5	71.52246	8.015676	51.27996	0.044090	0.139163	0.088623	0.030133	0.214711
12	9591.5	9613.5	70.10292	8.015415	58.64432	0.074310	0.146376	0.091698	0.030640	0.212349
13	9613.5	9635.25	79.45863	8.011284	23.24289	0.007860	0.316555	0.063080	0.044575	0.164131
14	9635.25	9649.75	99.03932	8.020169	49.09854	0.040015	0.122497	0.088106	0.027777	0.234960
15	9649.75	9681.75	63.09116	8.009837	103.9402	0.028506	0.095665	0.077053	0.022374	0.196616
16	9681.75	9712.25	53.68682	8.011357	63.82216	0.021076	0.145843	0.064879	0.027932	0.169249
17	9712.25	9719.5	37.02933	8.011733	107.143	0.01545	0.114417	0.065478	0.026105	0.147889
18	9719.5	9742.75	50.89531	8.018074	89.82740	0.075723	0.094523	0.085882	0.024626	0.201263
19	9742.75	9763	58.66487	8.013609	84.03520	0.035168	0.135018	0.061822	0.025916	0.162026
20	9763	9774.75	43.16666	8.005770	86.04347	0.004662	0.207311	0.050723	0.035142	0.103597
21	9774.75	9792.25	53.76450	8.007774	79.32535	0.007904	0.184445	0.055557	0.031726	0.137557
22	9792.25	9796.5	106.1088	8.013833	30.49188	0.020277	0.246204	0.071603	0.041355	0.177075
23	9796.5	9812.5	70.82030	8.010492	73.23206	0.037458	0.154663	0.076694	0.030787	0.197558
24	9812.5	9818.25	36.67166	8.015916	130.4875	0.035191	0.147381	0.067184	0.033797	0.151711
25	9818.25	9832.75	78.97966	8.012610	42.23298	0.149684	0.131696	0.102126	0.031917	0.243511
26	9832.75	9840.25	83.79612	8.013387	65.10116	0.099219	0.091106	0.093749	0.024533	0.229505
27	9840.25	9870.75	73.44130	8.012430	52.17316	0.137343	0.192556	0.082724	0.035916	0.192824
28	9870.75	9897.5	53.81518	8.059388	83.97175	0.034374	0.191571	0.062743	0.034536	0.146026
29	9897.5	9942.5	72.80132	8.111138	43.24962	0.046584	0.328971	0.068526	0.047131	0.176511
30	9942.5	9968.75	56.32981	8.116226	33.09848	0.027893	0.320209	0.059511	0.044229	0.159047
31	9968.75	9987.5	45.37736	8.109539	139.3513	0.030565	0.233965	0.065711	0.041915	0.135760
32	9987.5	10026.75	90.42962	8.113246	26.56040	0.095877	0.532524	0.072952	0.061858	0.214592
33	10026.75	10070.5	94.17659	8.112795	6.436875	0.040952	0.723187	0.063356	0.062284	0.204870
34	10070.5	10122.75	96.87142	8.112838	7.464666	0.074176	0.536833	0.074261	0.060708	0.243295
35	10122.75	10165	101.0284	8.108605	5.254511	0.055701	0.730204	0.066496	0.066024	0.233925
36	10165	10191	115.6464	8.119857	4.401257	0.047926	0.761679	0.068673	0.067965	0.253186
37	10191	10226	106.7234	8.106886	4.006680	0.026502	0.816459	0.065461	0.064669	0.265194

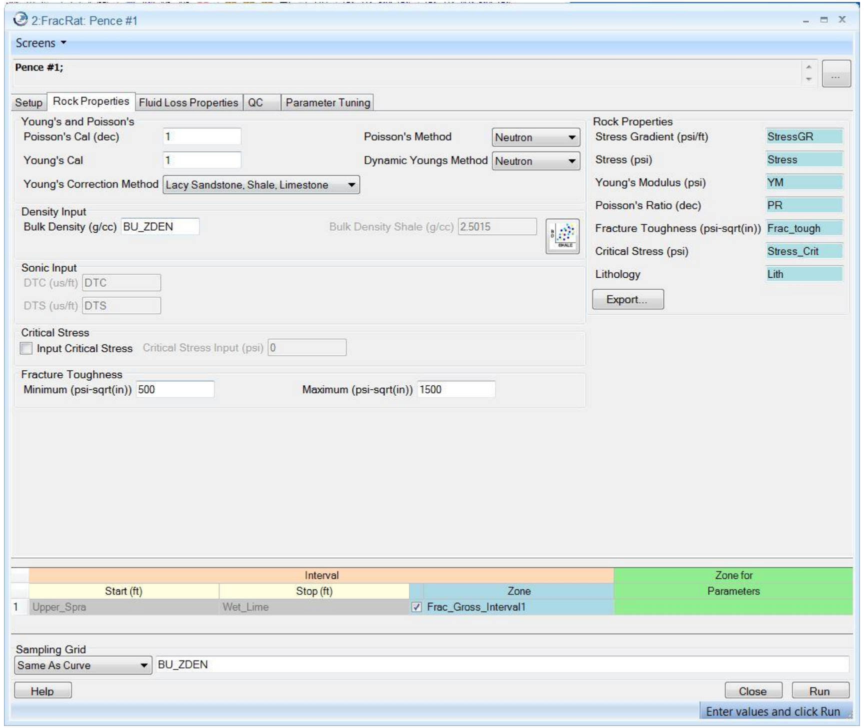
FracRAT Module Setup Tab (Tab 1)



Select the curve data for input and set up parameters for determining many of the essential parameters for use in frac simulation

Has multiple options for computing Vsh and calculating permeability including allowing externally generated curve data.

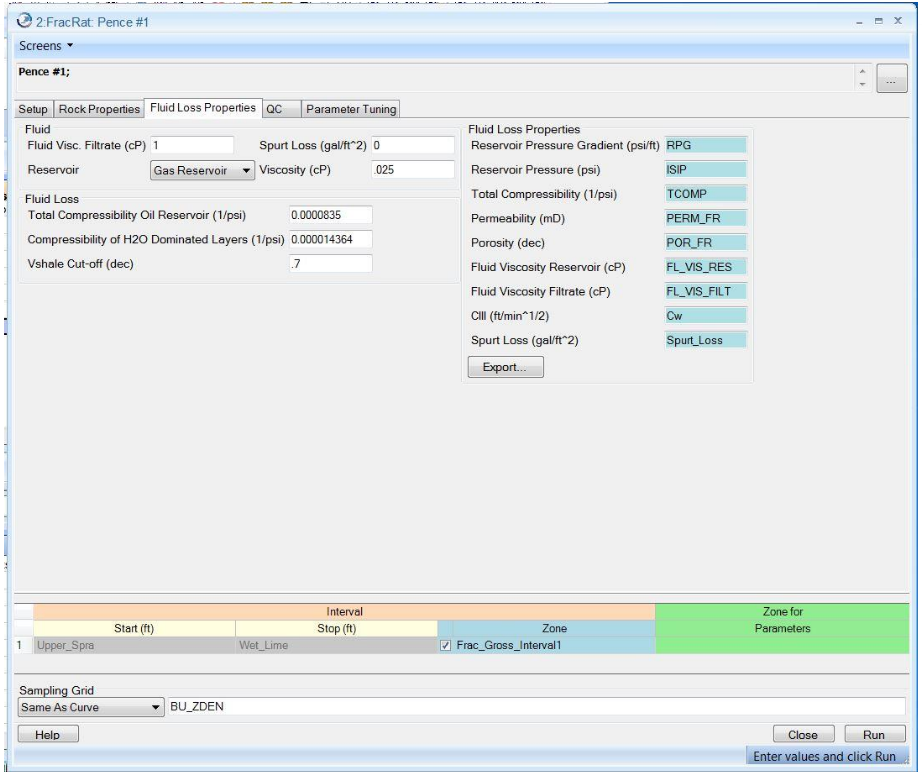
FracRAT Module Rock Properties Tab (Tab 2)



Choose the methodologies for computing Poisson’s Ratio and Young’s Modulus and set a range for fracture toughness

Generates the rock properties

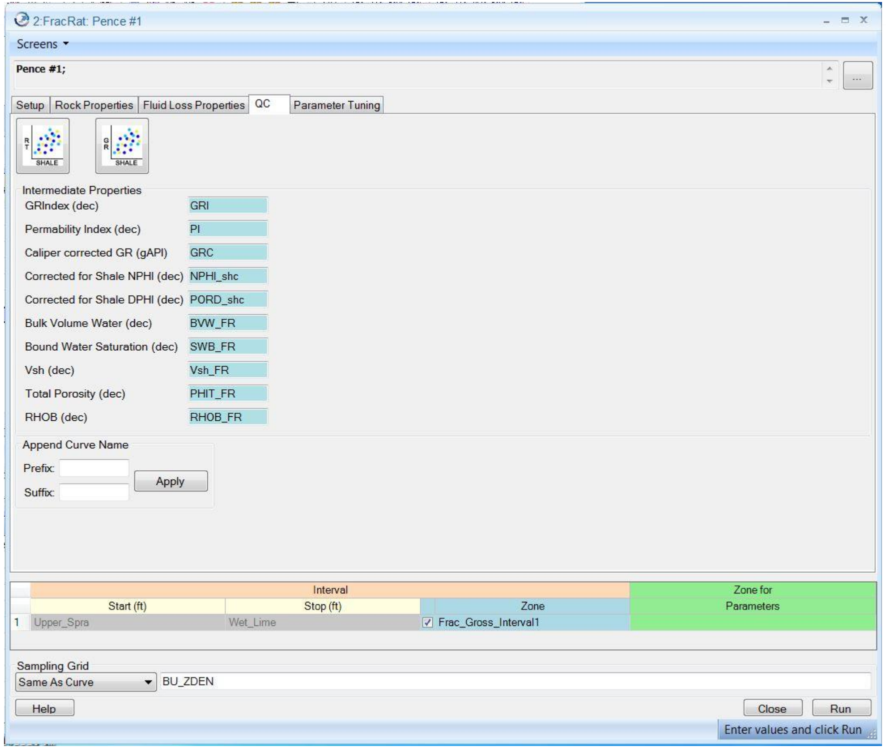
FracRAT Module Fluid Loss Properties (Tab 3)



Input the physical parameters like compressibility and viscosity for the fluids in the reservoir and mud.

Generates the fluid loss properties

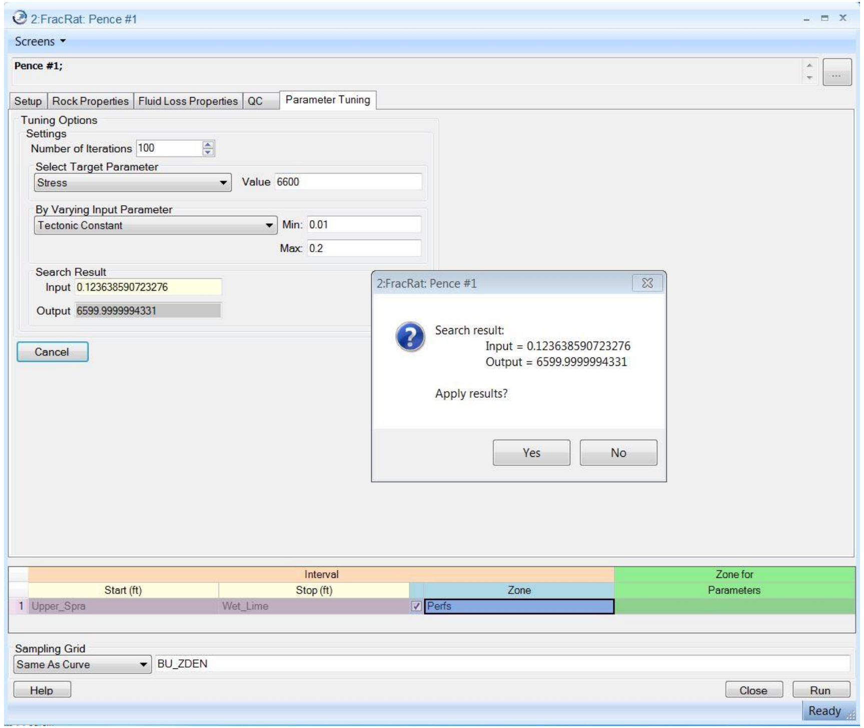
FracRAT Module QC Tab (Tab 4)



Outputs the transient curves used in the generation of the rock and fluid properties.

Enables users to insure quality of results

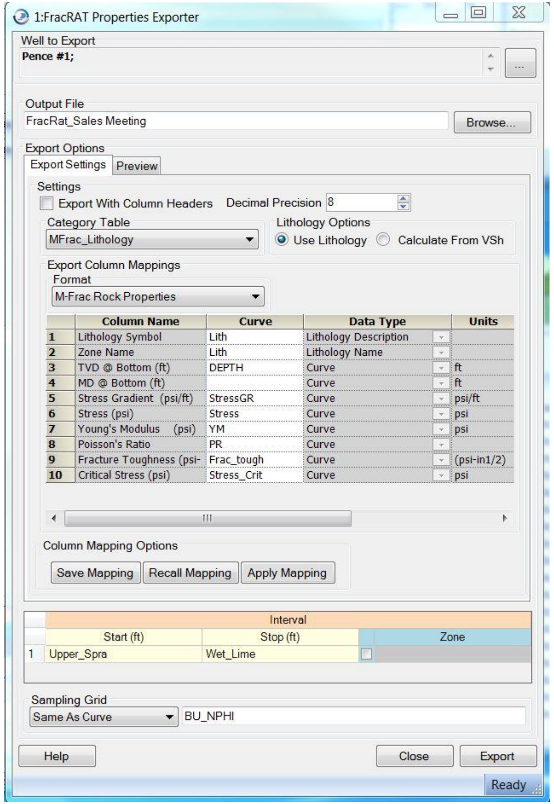
FracRAT Module Parameter Tuning Tab (Tab 5)

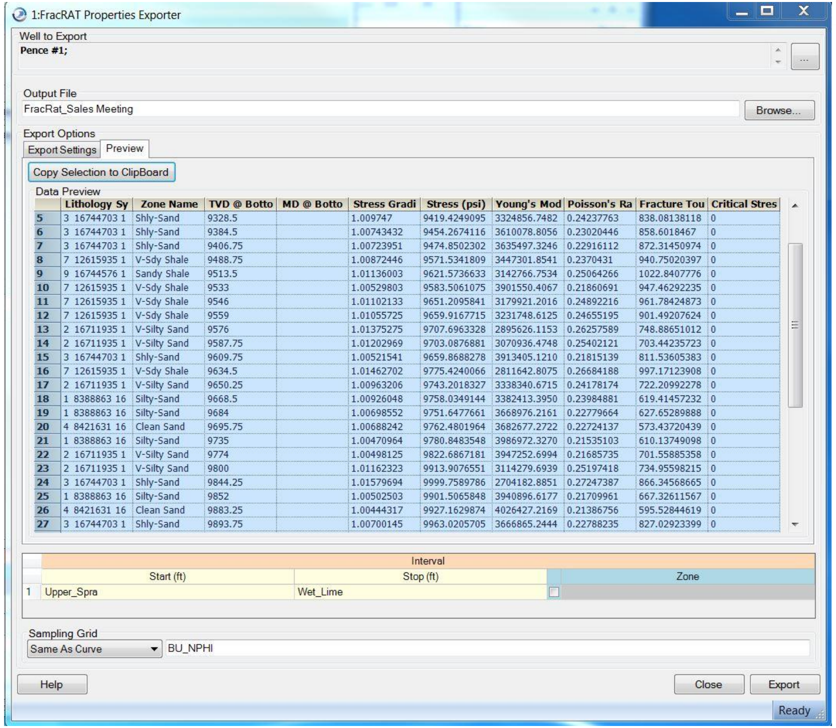


Important feature that will take known data from Minifrac Tests and give the user the ability to determine the exact input parameters required to match Minifrac results.

Essential in assuring valid simulation models

FracRAT Exporter





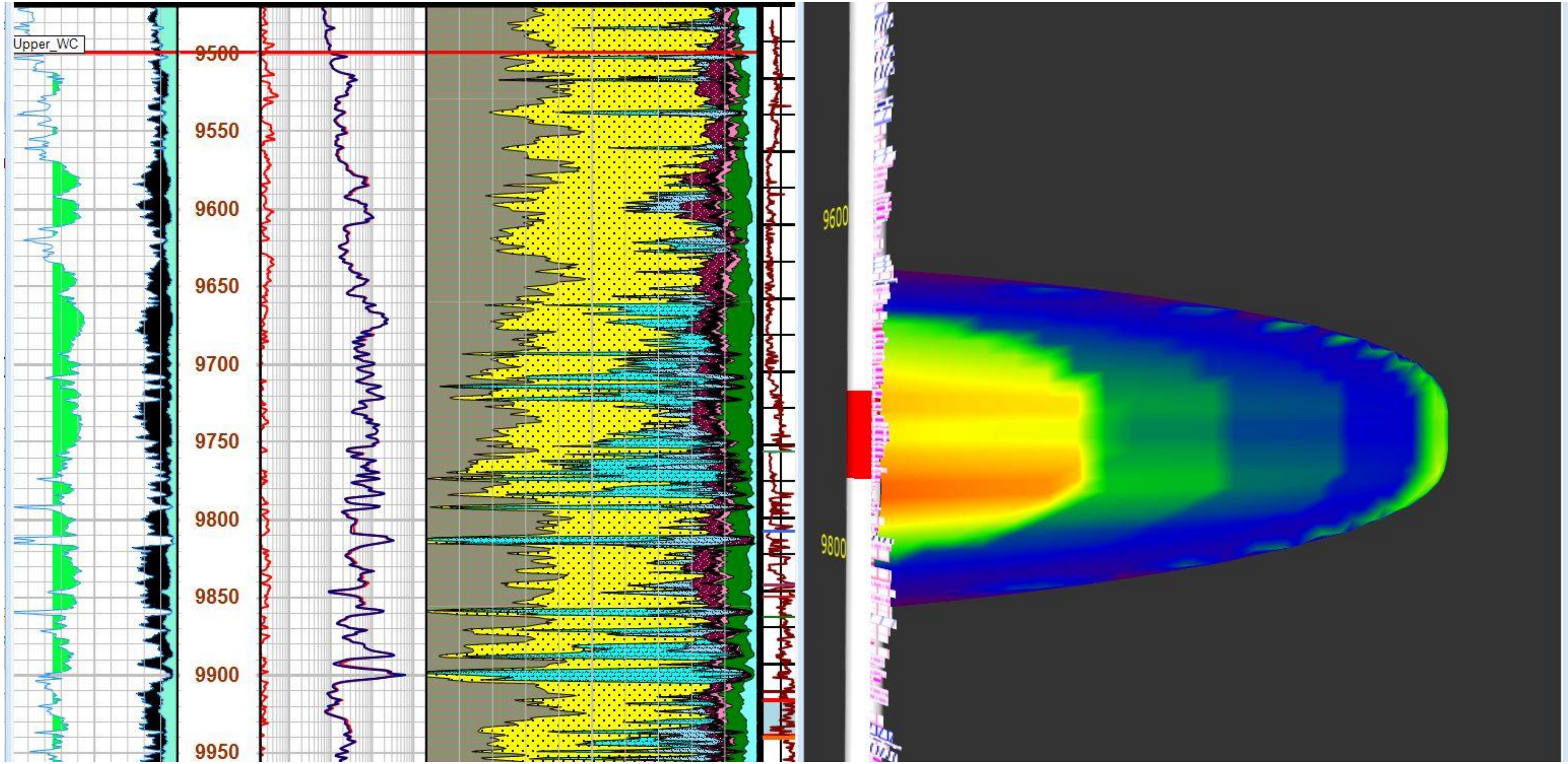
MFrac Rock Properties

Rock Properties

	Lithology Symbol	Zone Name	TVD at Bottom (ft)	MD at Bottom (ft)	Stress Gradient (psi/ft)	Stress (psi)	Young's Modulus (psi)	Poisson's Ratio	Fracture Toughness (psi-in^½)	Critical Stress (psi)	Int G
1		V-Sdy Shale	9253	9253	1.01851	9424.24	1.1181e+07	0.285189	973.157	0	
2		V-Silty Sand	9304.75	9304.75	1.01087	9405.85	1.4303e+07	0.248129	778.457	0	
3		Shly-Sand	9344.5	9344.5	1.01249	9461.2	1.4235e+07	0.256317	840.621	0	
4		V-Silty Sand	9367	9367	1.01088	9468.92	1.4799e+07	0.248205	796.742	0	
5		Shly-Sand	9385.75	9385.75	1.01139	9492.67	1.5555e+07	0.250804	835.053	0	
6		V-Silty Sand	9430.75	9430.75	1.00847	9510.6	1.7469e+07	0.23569	760.046	0	
7		V-Sdy Shale	9451.5	9451.5	1.01423	9585.98	1.3885e+07	0.264904	902.826	0	
8		Shly-Sand	9472.25	9472.25	1.01394	9604.32	1.3825e+07	0.263509	892.471	0	
9		V-Sdy Shale	9499.75	9499.75	1.01531	9645.17	1.2967e+07	0.270131	916.173	0	
10		V-Sdy Shale	9534.25	9534.25	1.01419	9669.58	1.3888e+07	0.264738	902.537	0	
11		V-Silty Sand	9560.25	9560.25	1.01199	9674.88	1.3149e+07	0.253824	793.57	0	
12		Silty-Sand	9589.5	9589.5	1.00747	9661.12	1.5528e+07	0.230387	678.612	0	
13		Shly-Sand	9619	9619	1.01335	9747.38	1.336e+07	0.260579	852.34	0	
14		Silty-Sand	9657	9657	1.005	9705.26	1.7225e+07	0.216949	612.756	0	
15		Clean Sand	9688	9688	1.00171	9704.55	2.1513e+07	0.198314	541.481	0	
16		Clean Sand	9714	9714	1.00301	9743.26	1.8373e+07	0.205801	549.039	0	
17		Clean Sand	9750.25	9750.25	1.00213	9771.03	2.257e+07	0.200758	579.01	0	
18		Silty-Sand	9777.75	9777.75	1.00479	9824.58	1.8923e+07	0.215792	635.466	0	
19		V-Silty Sand	9821	9821	1.01087	9927.71	1.3182e+07	0.248155	752.263	0	
20		Clean Sand	9867.5	9867.5	1.00116	9878.91	2.3095e+07	0.195097	543.768	0	
21		V-Silty Sand	9902	9902	1.00956	9996.67	1.5419e+07	0.241413	760.052	0	
22		Clean Sand	9943.5	9943.5	1.00293	9972.61	2.0955e+07	0.205323	586.982	0	
23		Clean Sand	9967.75	9967.75	1.00063	9974	2.3625e+07	0.191987	526.393	0	
24		Sandy Shale	9995.25	9995.25	1.02146	10209.8	1.0134e+07	0.298567	1028.74	0	
25		Shly-Sand	10054	10054	1.01531	10207.9	1.2552e+07	0.270163	895.872	0	
26		Sandy Shale	10117.8	10117.8	1.02077	10327.9	1.0367e+07	0.295468	1010.52	0	
27		Silty-Shale	10166.3	10166.3	1.02878	10458.8	7.797e+06	0.329612	1145.14	0	
28		Silty-Shale	10223.3	10223.3	1.02878	10517.4	7.797e+06	0.329612	1145.14	0	
29											

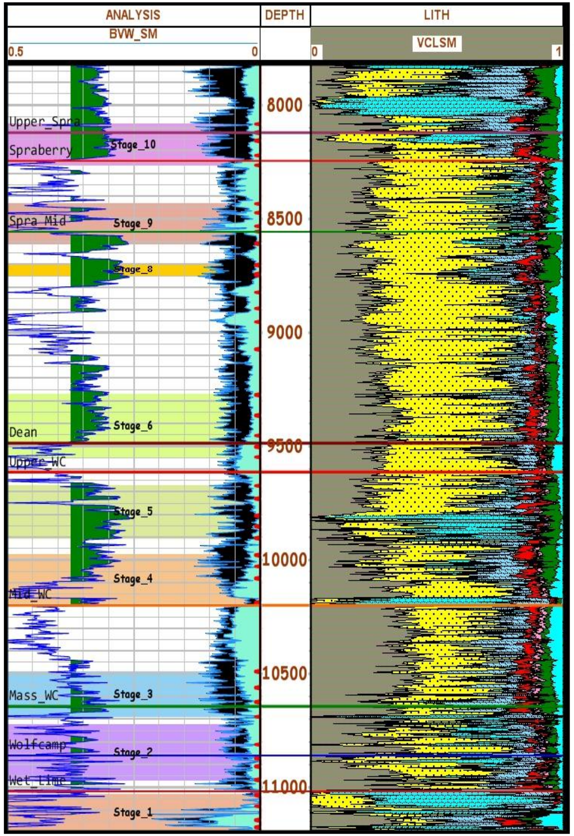
Insert from Database | Import Log | Plot | OK | Cancel | Help

Frac Simulation Results



Perforations, Frac Stages, and Production History

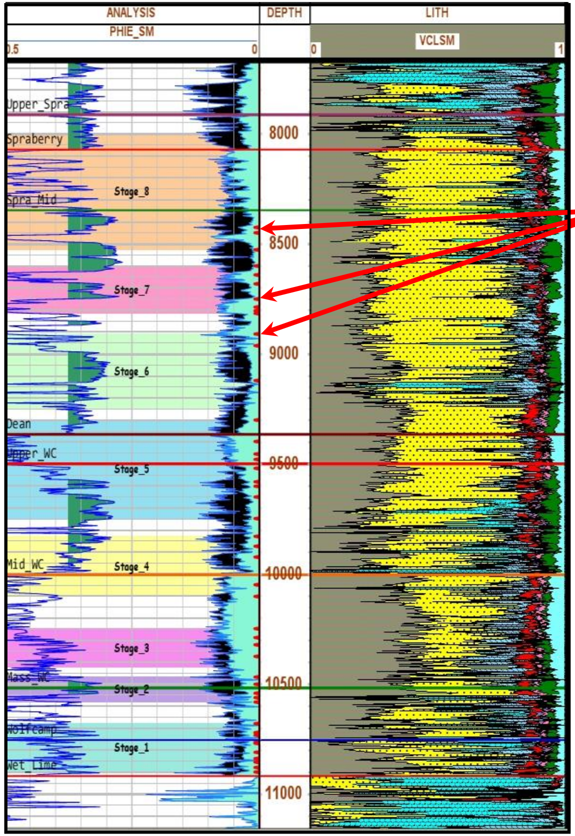
Frac Stages are colored intervals



Bourne #3

22 Months Production
18,705 bbls oil
18,817 mmcf gas
39,797 bbls Water

Currently making 624 bbls/month oil



Perforations

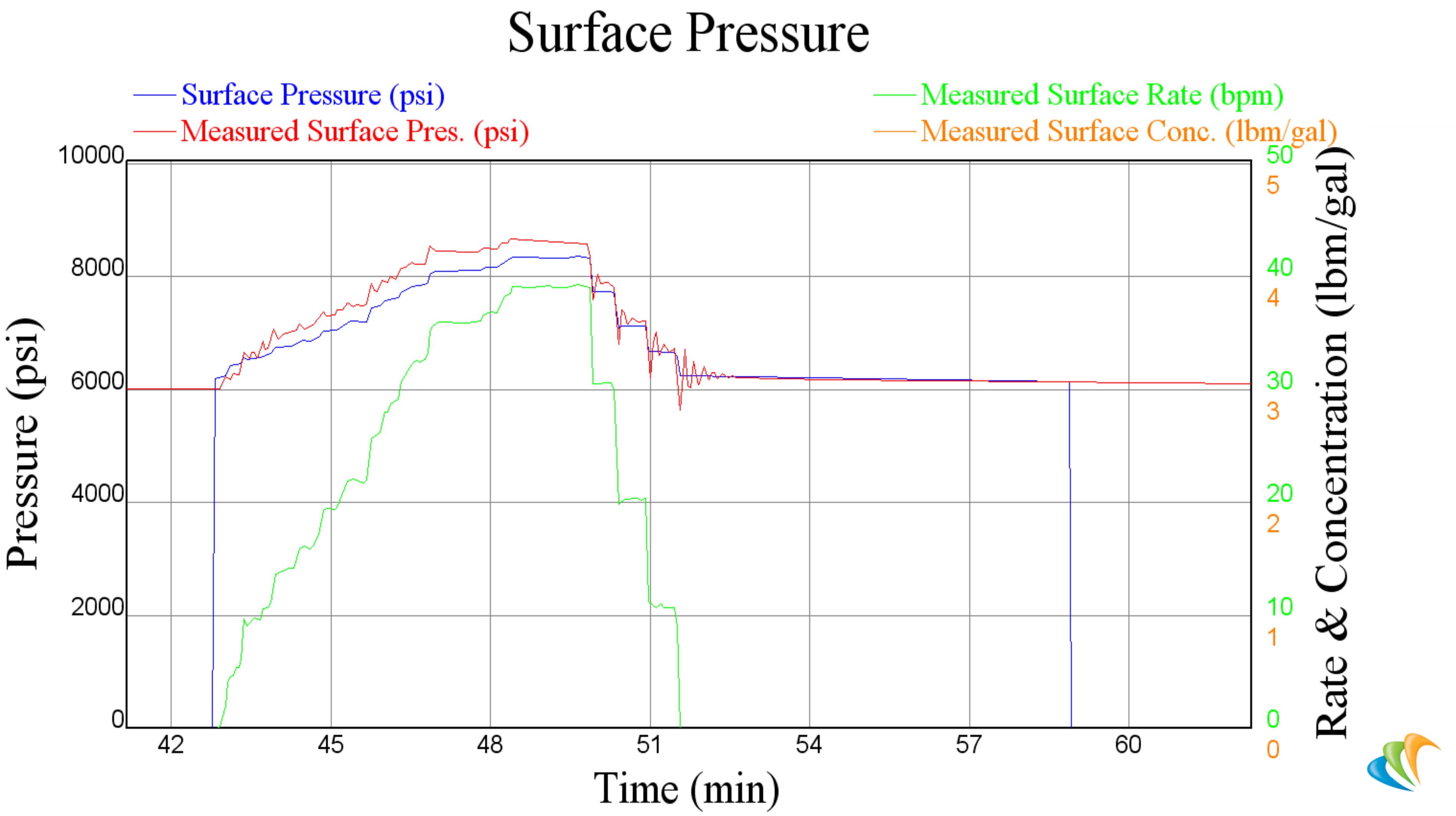
Pence #1

35 Months Production
38,464 bbls oil
51,518 mmcf gas
56,012 bbls Water

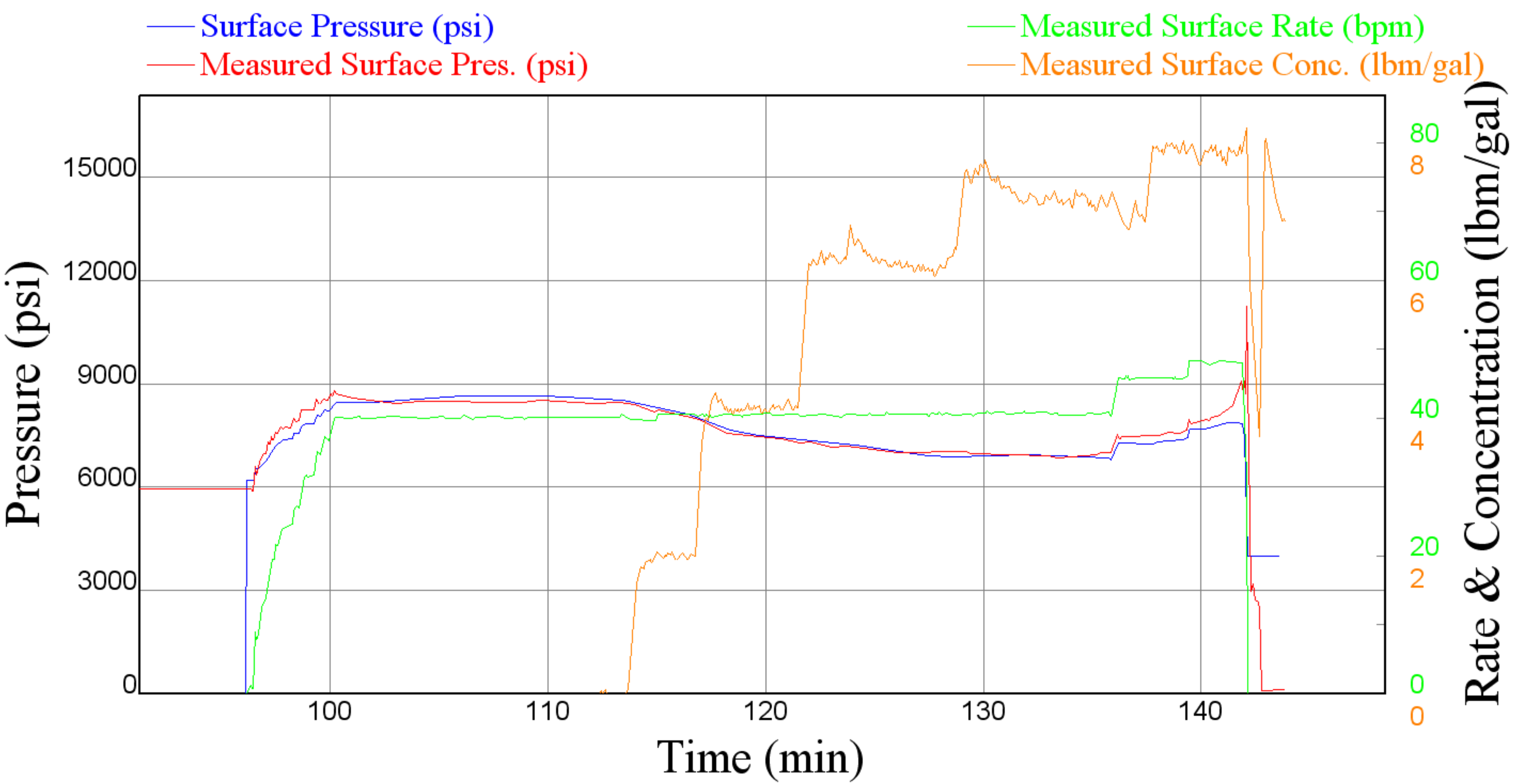
Currently making 485 bbls/month oil

Simulation to Stimulation Workfow

- Generate a simulation model based on best available data
- Mini-fracs are required to calibrate simulation models
- FracRAT has parameter tuning to calibrate simulation models
- Calibrated simulation models accurately predict frac stimulation results

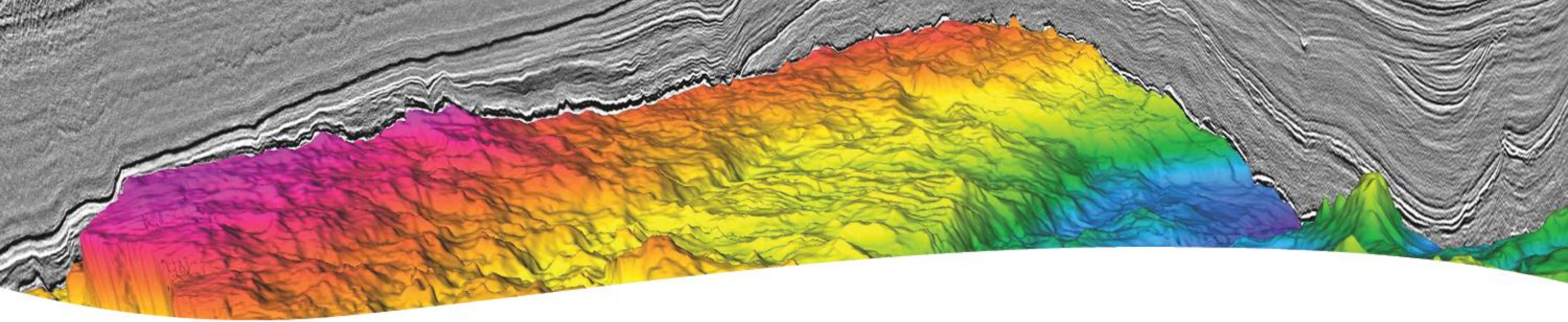

Surface Pressure
Surface Pressure (psi)
Measured Surface Pres. (psi)
Measured Surface Rate (bpm)
Measured Surface Conc. (lbm/gal)
Pressure (psi)
10000
8000
6000
4000
2000
0
42
45
48
51
54
57
60
Time (min)
Rate & Concentration (lbm/gal)
50
40
30
20
10
0
5
4
3
2
1
0

Surface Pressure



Conclusion

- Perf and frac everything is still a common practice when completing unconventional reservoirs
- Frac simulations are often not run for lack of data and the time involved in generating the models
- Petrophysical parameters are important factors in frac stimulation (and simulation) design
- The elastic properties needed as inputs to frac simulation can be deterministically or empirically derived.
- Tools like FracRAT can reduce the time needed to generate frac simulations
- Frac simulations should result in more effective fracs and improved commercial results



Thank you

geosoftware.info@cgg.com

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