Reservoir Characterization of Mississippian St. Louis Carbonate Reservoir Systems in Kansas, Stratigraphic and Facies Architecture Modeling

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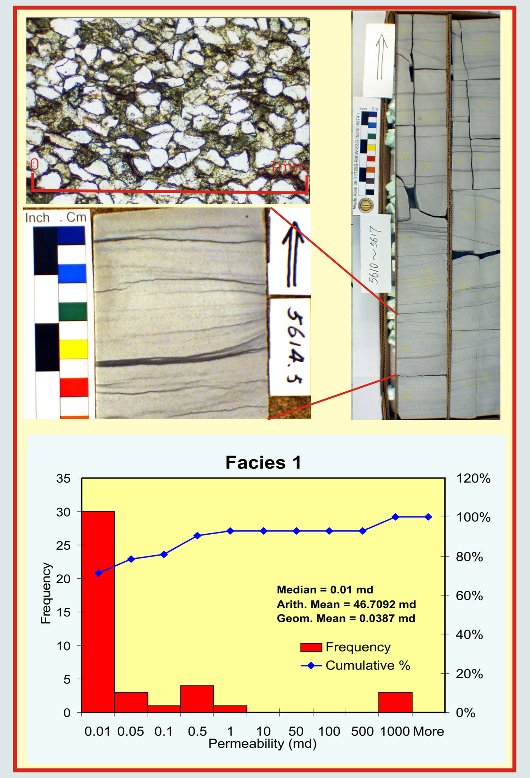
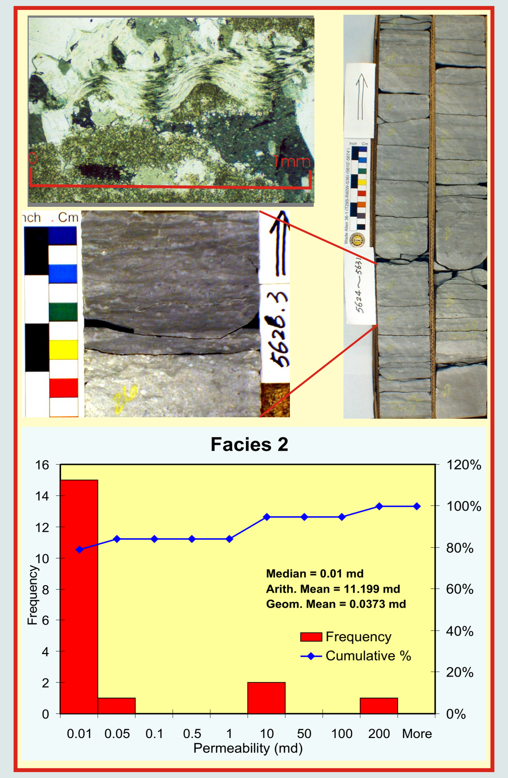
Lithofacies Classificatoins



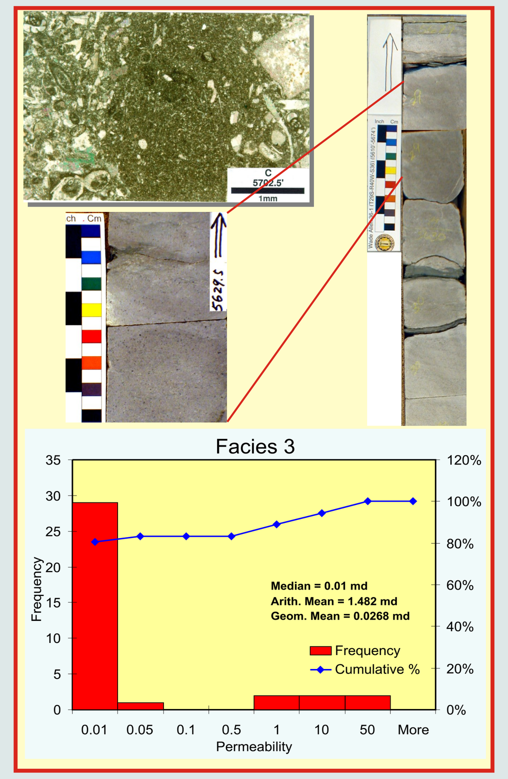
Cross-bedded Quartz-rich Carbonate Grainstone

Mixed siliciclastic and carbonate grainstone contains very fine quartz (up to 40 ~ 50 percent) and medium grained peloids, skeletal fragments, ooids with micrite and calcite spar cement. Compactional effects, broken ooids, oriented grains, calcite-filled fractures and minor dissolution of grains are evident. Inverse translatent stratification, stylolites, are common. Occasional root structures are observed. Angles of cross bedding most commonly are in the 10 to 20 degree range. Permeability is less than 1md, most <0.01md. Non-reservoir facies.



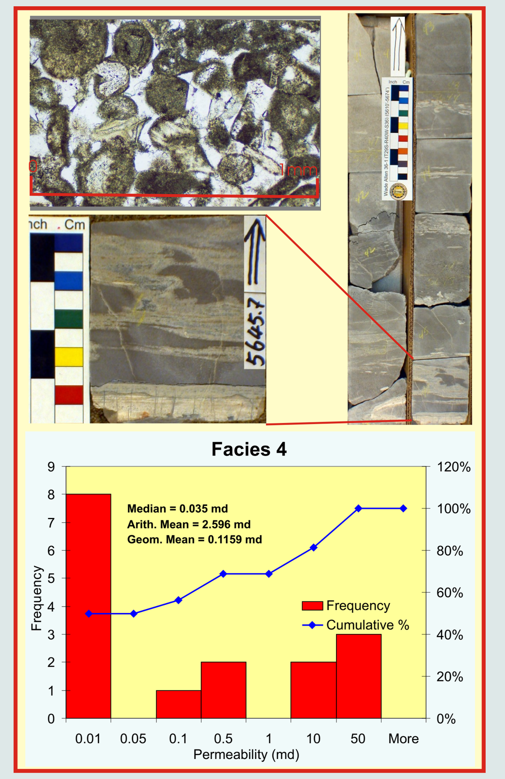
Argillaceous Limestone

Thin, laterally extensive condensed section, characterized by thinly beded, often fissile olive green to gray argillaceous limestones which is primarily wackestone /packstone with abundant bryozoans and crinoids and minor brachiopods and ostracods. Occasionally contains small amount of very fine to medium detrital quartz. On electronic logs, it shows a distinctively higher gamma-ray response. Non-reservoir facies.



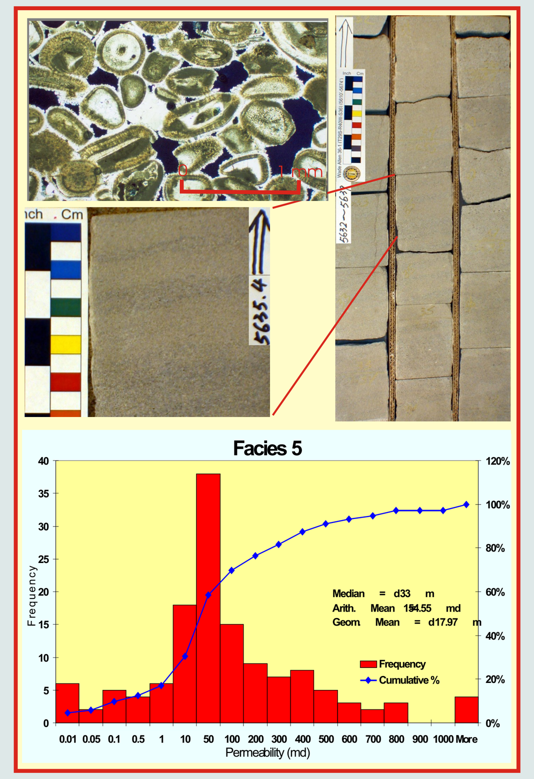
Skeletal Wackestone

Very poorly sorted, and greenish to dark yellowish-brown in color with large, relatively un-abraded skeletal fragments. Crinoids and fenestrate bryozoans are the most abundant skeletal fragments, with echinoderms, brachiopods, gastropods and foraminifera also present. Porosity averages lass than one percent, with permeability of 0.01 md. Non-reservoir facies.



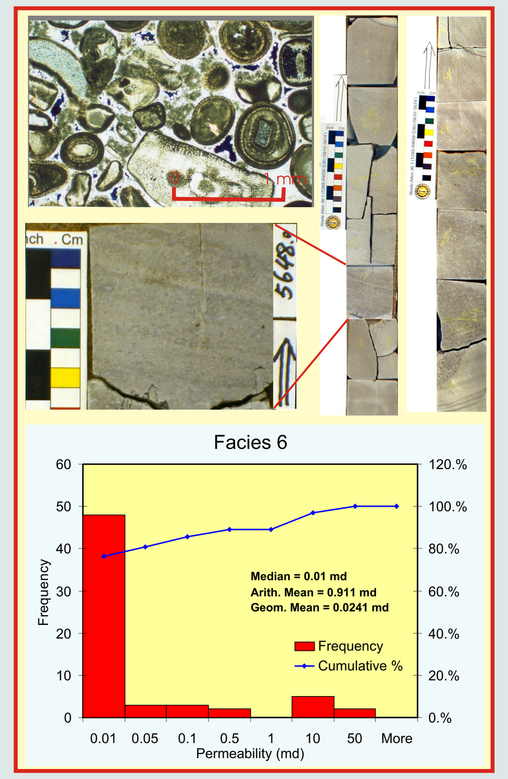
Peloidal Grainstone/Packstone /Fenestral Limestone

This Lithofacies deposited in back barrier lagoon or tidal flat and composed of very fine peloidal grains, with some very fine quartz, and fine ooid grains present. The fenestral limestone is characterized by "bird's-eye" or fenestral fabric (indicator of intertidal to supratidal deposition). Large vugs, filled with anhydrite or chert or calcite spar, can be seen. Typically occurs adjacent to the ooid-skeletal grainstone facies. Sometimes, mud cracks can be observed at the top of the sequence. Non-reservoir facies.



Ooid Skeletal Grainstone

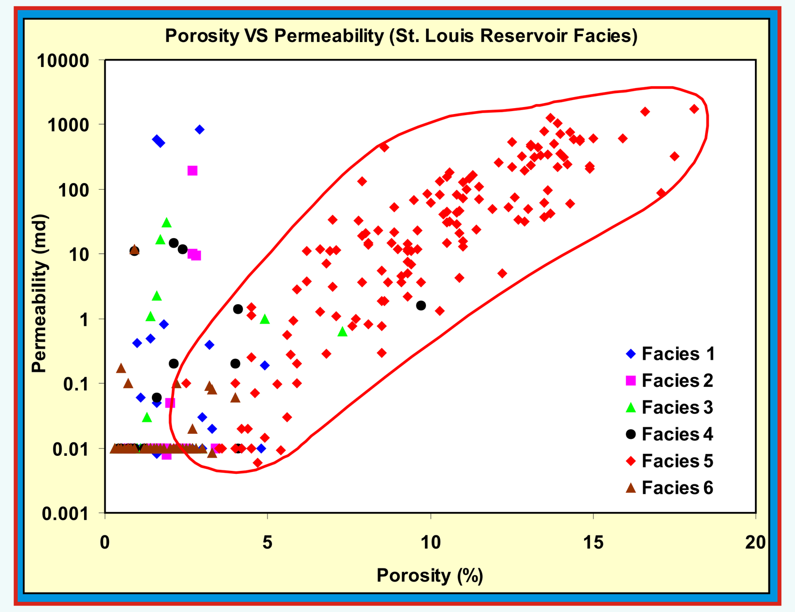
This lithofacies is the reservoir unit and is characterized by very coarse to medium size moderately sorted ooids. The ooids have a radial concentric structure and are usually unbroken. Large skeletal grains, peloids present. Main porosity is interparticle porosity with minor moldic porosity. Total porosity can vary from 3 percent to as high as 20 percent. Distinctive log response with higher porosity and lower resistivity. Accumulates in a high-energy, open-marine environment. Reservoir facies.



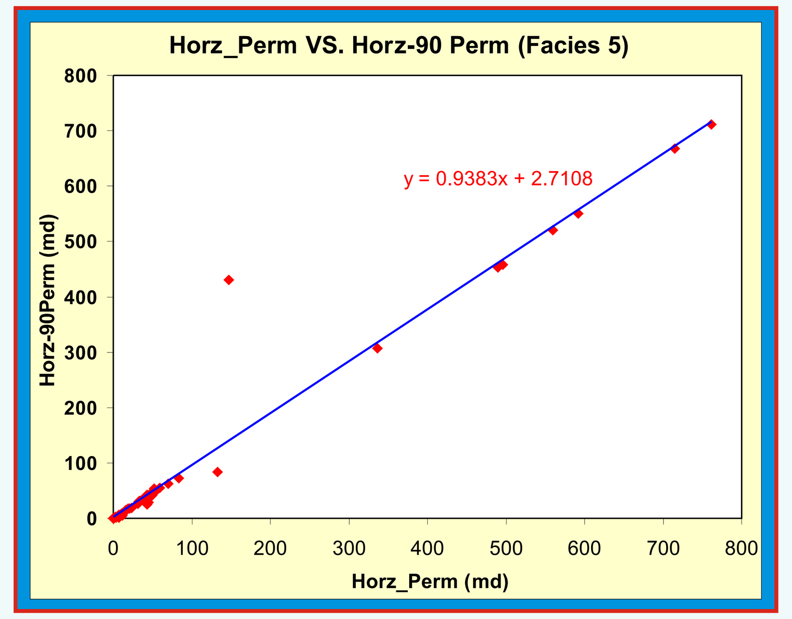
Cemented Ooid Skeletal Grainstone

Composed of very coarse to medium size and moderately sorted ooids. The ooids have a radial concentric structure and are usually unbroken. Large skeletal grains and peloids are present. Heavy syntaxial cementation occludes interparticle voids. Porosity and permeability are very poor. Non-reservoir facies.

Lithofacies Petrophysics

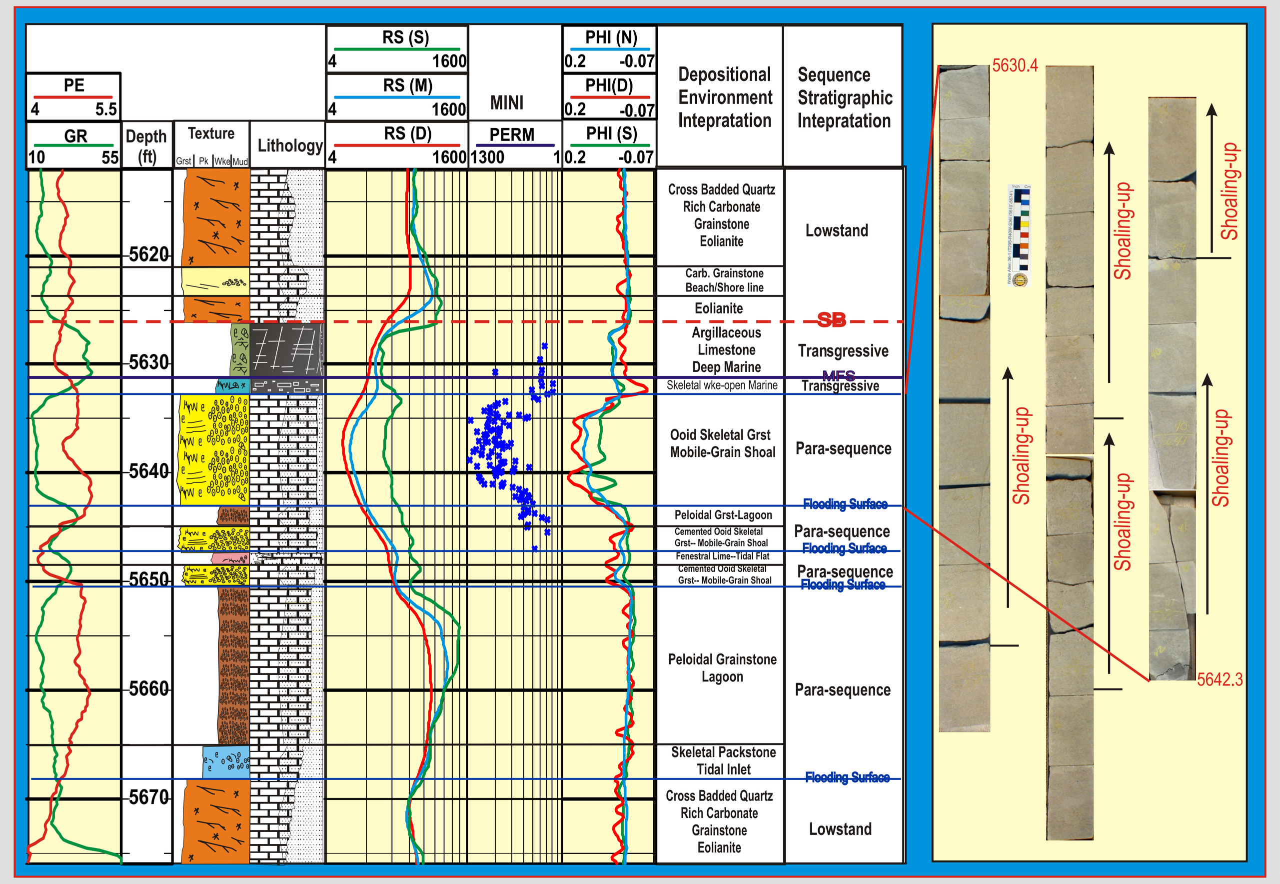


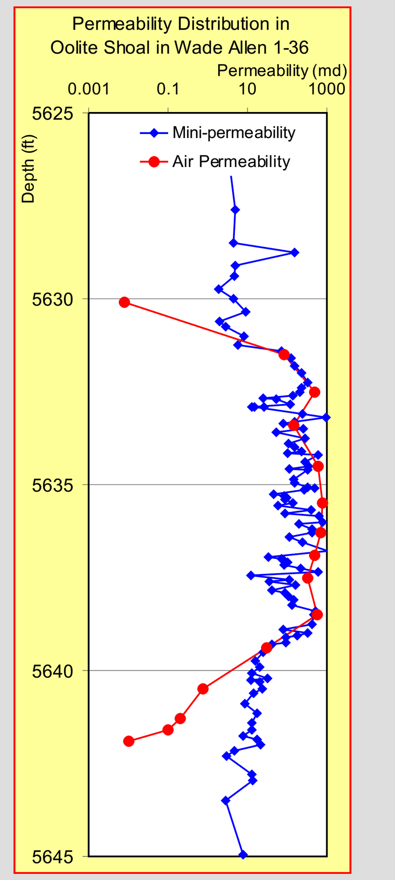
Porosity distribution of facies 5 (reservoir facies) ranges from more than 3% to around 20%. The main porosity type is primary inter-granular porosity. The porosity of other facies (non-reservoir facies) is mainly less than 3%. This figure shows an exponential relationship between core porosity and core permeability.

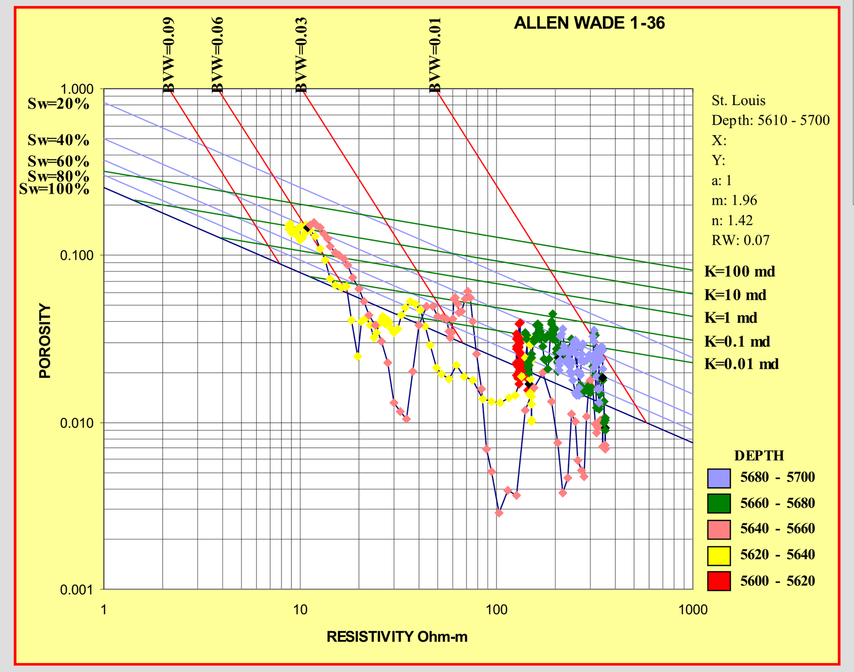


Based on limited available data, a linear relationship exists between the horizontal permeability and 90 degree horizontal permeability in the reservoir facies--ooid skeletal grainstone. It indicates the lateral connectivity within oolite shoals are good, whereas the vertical connectivity varies depending on the degrees of cementation among layers with more elongate skeletal particles.

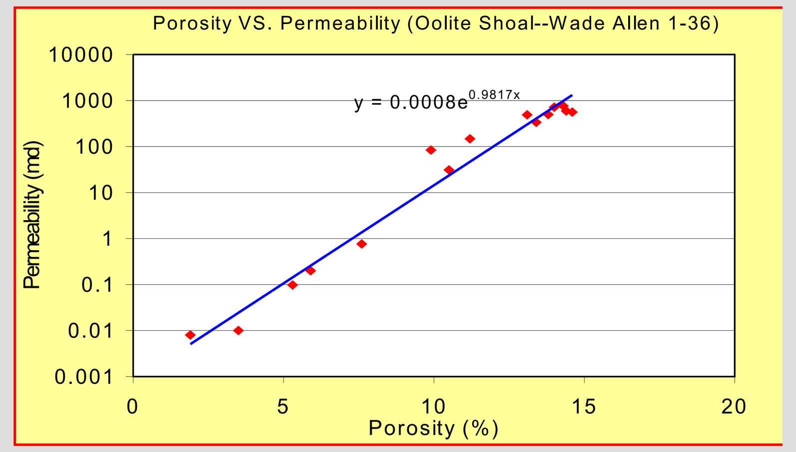
St. Louis Oolite Shoals Cored Well Wade Allen 1-36







The pay zone, oolitic shoal interval, has a log response with the lowest RT value and highest porosity on log. Porosity shows an exponential relationship with permeability based on available data. Porosity distribution the ranges from 0.02 to 0.15. However, the distribution of permeability displays high heterogeneity, from less than 0.01 to more than 1,000md.



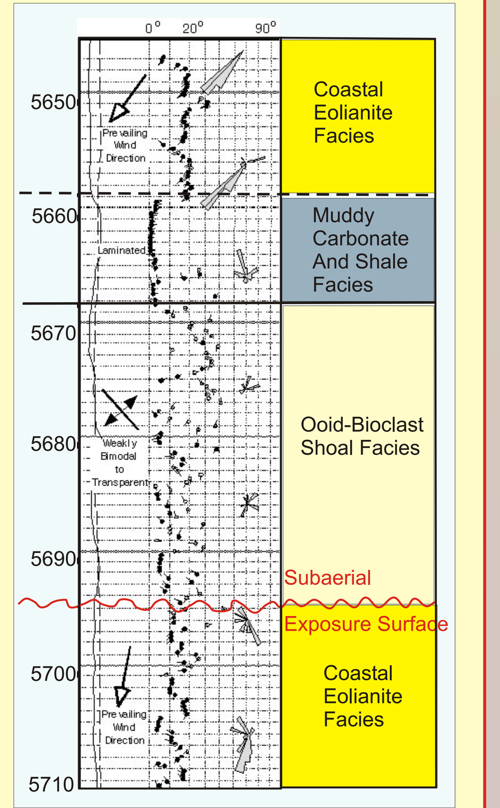
Data types:

1. Core data: 15 wells, up to 600 ft of core, are available. 6 main lithofacies are recognized and classified based on core description and thin sections.

2. Log data: about 200 wells have digital logs, including GR, Resistivity log, density, porosity (neutron & density porosity) and PE. Several wells have stratigraphic dipmeter logs.

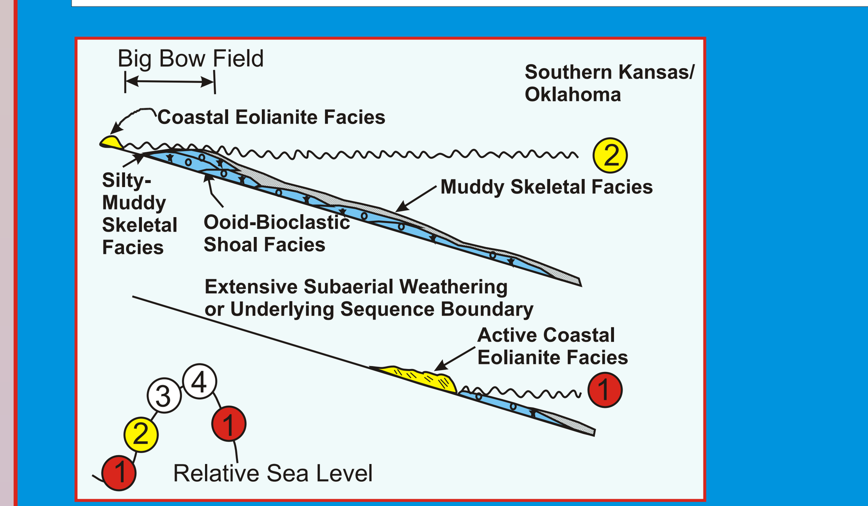
3. Petrophysical data: 10 wells have measured porosity and permeability data. Mini-perm have been measured within the ooid shoal interval in two wells.

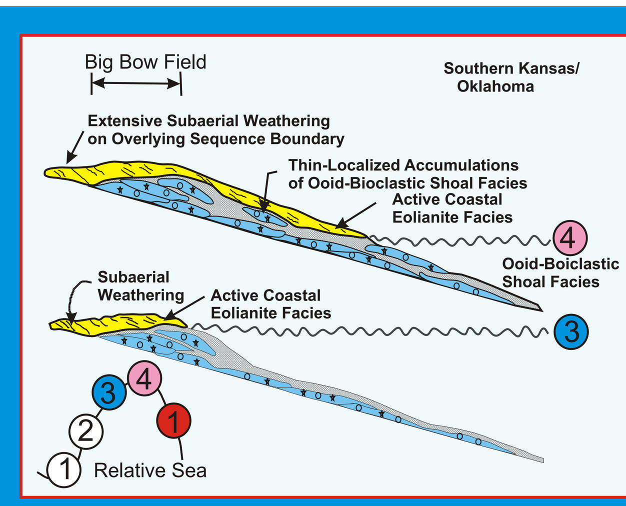
Stratigraphic Dipmeter



Siebert #2, Sec. 22, T29S, R38W
Grant Co., Kansas; ARCO Oil & Gas Co.

Sequence Stratigraphic Model





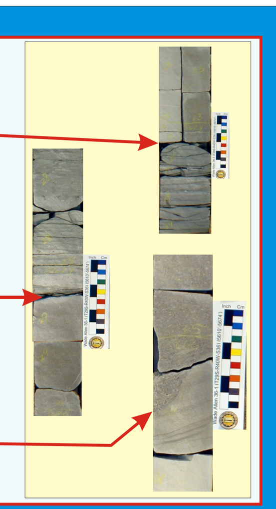
Stratigraphic Surfaces and Log Response

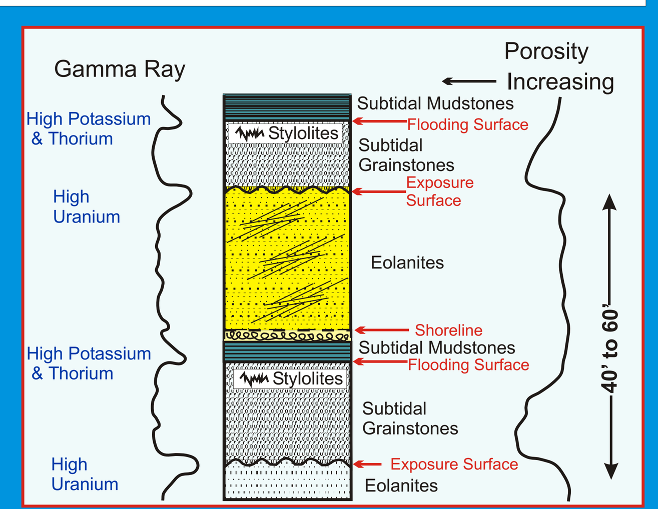
Main Stratigraphic Surfaces

1. Sequence Boundary (SB): Cross-bedded quartz-rich carbonate grainstone sit on top of deep marine limestone.

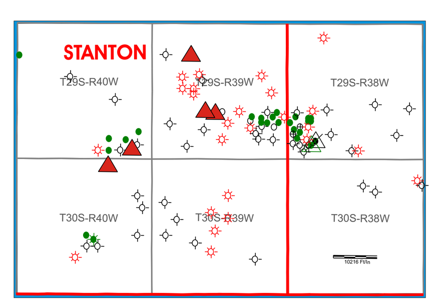
2. Maximum Flooding Surface (MFS): Argillaceous Limestone deposited at the top of skeletal wackestone or oolitic grainstone.

3. Flooding Surface (FS): Skeletal wacke/packstone contacted with quartz-rich carbonate grainstone (eolianite) at the bottom.

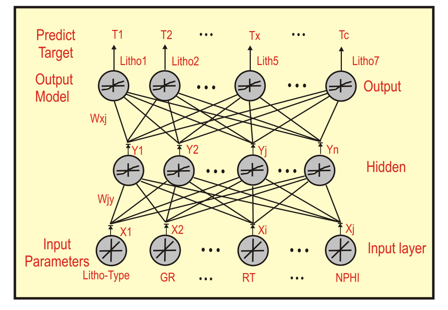




Lithofacies Prediction



lithofacies have been recognized and described from 15 cored wells. Five key core wells (red triangles in the figure) in Big Bow and Sand Arroyo Creek Fields were chosen to build the Neural Network model.



Determined predictor variables (GR, IDID, IDIM, PE, Neutron/Density Porosity and lithofacies categories were inputted into Kipling to build Neural Network models. The size of network and dampling parameters were optimized using cross-validation and repeatedly tested with whole training data and randomly chosen partial of whole data set.

Predicted Lithofacies Scorecard (Counts) for five key trained core wells without PE curve

Actuaral Lithofacies (columns); Predicted Lithofacies (rows)

Lithofacies Type	1	2	3	4	5	6	7	Grand Total
1	497	3		3	1	3	2	509
2	2	103		1			1	107
3			12					12
4	13			122	1	12	3	151
5				2	92			94
6	12		2	2	1	94		111
7	13			2			40	55
Grand Total	537	106	14	132	95	109	46	1039
Pred/Actuaral	0.926	0.9717	0.857	0.924	0.968	0.862	0.87	

The results of model with network size (number of hidden layers) 20 and dampling parameter 0.05 for five key wells without PE log.

Predicted Lithofacies Scorecard (Counts) for five key trained core wells with PE curve

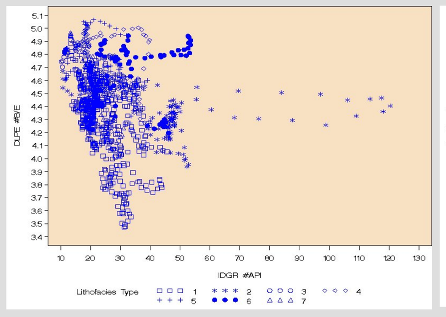
Actual Lithofacies (columns); Predicted Lithofacies (rows)

Lithofacies Type	1	2	3	4	5	6	7	Grand Total
1	502					2	5	509
2	2	104				1		107
3		1	11					12
4	6			132		13		151
5	3			1	90			94
6	5		2	7		96	1	111
7	10			1			44	55
Grand Total	528	105	13	141	90	112	50	1039
Pred/Actural	0.951	0.99	0.846	0.936	1.00	0.857	0.88	

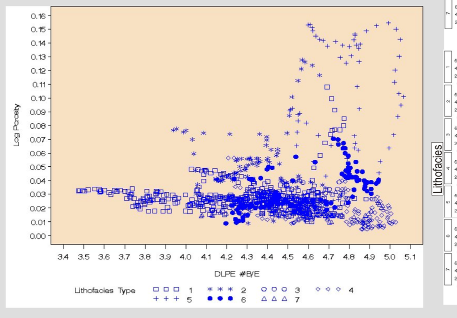
The results of model with network size (number of hidden layers) 20 and dampling parameter 0.05 for five key wells with PE log. It shows a slight better prediction/actural rate with PE logs than without PE logs.

Statistical Analysis of Predictor Variables (GR, IDIM, IDID, PE and Log Porosity) by Lithofacies Types

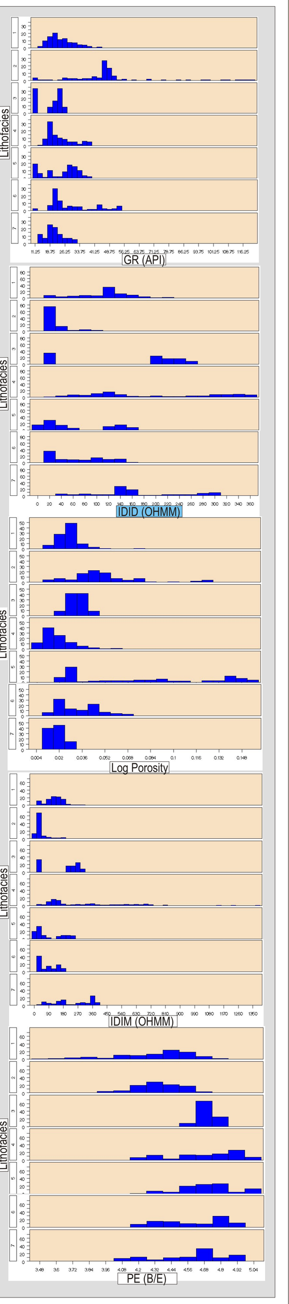
Litho Type	No Obs	Variable	Mean	Std Dev	Std Error	Variance	N	Minimum	Maxmum	Median	Range	Sum
1	509	GR (API)	24.53065	6.551287	0.290381	42.91936	509	13.4821	45.6511	23.0294	32.169	12486.1
		IDIM	128.6969	58.55246	2.595292	3428.39	509	18.8295	357.2844	132.1738	338.4549	65506.73
		IDID	114.1554	46.48365	2.060351	2160.73	509	19.2626	282.3079	121.5432	263.0453	58105.09
		PE (B/E)	4.311731	0.285626	0.01266	0.081582	509	3.4743	4.9169	4.3843	1.4426	2194.67
		Log_Phi	0.02716	0.010648	0.000472	0.000113	509	0.0101	0.108014	0.026489	0.097914	13.82427
2	107	GR (API)	48.49241	21.88198	2.115411	478.8213	107	10.7431	120.4609	46.7938	109.7178	5188.69
		IDIM	35.99753	35.39252	3.421524	1252.63	107	13.4974	175.8676	22.0363	162.3702	3851.74
		IDID	28.4744	19.31776	1.867518	373.1758	107	13.7989	93.9097	21.0539	80.1108	3046.76
		PE (B/E)	4.347271	0.168024	0.016244	0.028232	107	3.9391	4.6701	4.349	0.731	465.158
		Log_Phi	0.050008	0.024398	0.002359	0.000595	107	0.009114	0.127746	0.044493	0.118632	5.350806
3	12	GR (API)	18.97439	6.333412	1.828298	40.1121	12	10.2784	25.7447	21.5374	15.4663	227.6927
		IDIM	179.7169	108.2994	31.26336	11728.77	12	36.8966	293.9465	224.8855	257.0499	2156.6
		IDID	157.5153	101.011	29.15935	10203.22	12	21.7274	258.6658	204.4415	236.9384	1890.18
		PE (B/E)	4.683	0.056499	0.01631	0.003192	12	4.5744	4.7806	4.6754	0.2062	56.196
		Log_Phi	0.031843	0.006893	0.00199	4.75E-05	12	0.019268	0.043155	0.032294	0.023887	0.382111
4	151	GR (API)	23.65168	6.589459	0.536243	43.42097	151	14.9203	39.8662	20.8389	24.9459	3571.4
		IDIM	312.7038	252.837	20.57558	63926.55	151	34.6873	1392.63	193.9095	1357.94	47218.27
		IDID	193.7841	106.1637	8.639481	11270.74	151	27.8908	360.4768	148.3883	332.586	29261.4
		PE (B/E)	4.680099	0.247492	0.020141	0.061252	151	4.1804	5.0272	4.7435	0.8468	706.6949
		Log_Phi	0.017848	0.010088	0.000821	0.000102	151	0.004511	0.056395	0.015315	0.051884	2.694969
5	94	GR (API)	24.22432	8.506395	0.877368	72.35875	94	11.5738	39.1622	27.18755	27.5884	2277.09
		IDIM	86.90732	83.96035	8.659849	7049.34	94	11.9363	238.1049	41.67865	226.1686	8169.29
		IDID	62.01261	56.88744	5.867491	3236.18	94	8.7641	153.9297	38.17615	145.1656	5829.18
		PE (B/E)	4.70371	0.200306	0.02066	0.040123	94	4.2417	5.0674	4.69	0.8257	442.1487
		Log_Phi	0.076241	0.048918	0.005046	0.002393	94	0.019828	0.154445	0.066216	0.134617	7.166649
6	111	GR (API)	29.60201	11.34525	1.076843	128.7147	111	11.3258	53.5982	24.0398	42.2724	3285.82
		IDIM	83.87752	55.47657	5.265603	3077.65	111	19.6756	175.7563	77.8926	156.0807	9310.4
		IDID	67.87586	43.7258	4.15027	1911.95	111	17.1854	163.6479	63.5163	146.4625	7534.22
		PE (B/E)	4.593383	0.232539	0.022072	0.054075	111	4.1965	4.9452	4.6212	0.7487	509.8655
		Log_Phi	0.033307	0.014575	0.001383	0.000212	111	0.008961	0.07059	0.028268	0.061629	3.697067
7	55	GR (API)	21.01866	4.716644	0.635992	22.24673	55	13.3141	31.099	20.2536	17.7849	1156.03
		IDIM	239.2579	114.2638	15.40733	13056.22	55	38.5934	380.5188	265.9912	341.9254	13159.18
		IDID	166.058	73.40164	9.897475	5387.8	55	34.3387	295.3645	149.822	261.0258	9133.19
		PE (B/E)	4.596264	0.252246	0.034013	0.063628	55	4.0756	4.9652	4.6764	0.8896	252.7945
		Log_Phi	0.018408	0.004698	0.000633	2.21E-05	55	0.009861	0.031995	0.017967	0.022134	1.01245



PE vs. GR by Lithofacies



Log Porosity vs. PE by Lithofacies



Predicted Lithofacies Results for Five Key Cored Wells