Evaluation of well completions opportunities in the lower Brushy Canyon using Neural Networks

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Abstract

Estimation of water saturations, in most cases, is primarily based on wire-line logs because they are relatively inexpensive and easily obtained. However, thin-bedded turbidities can pose difficulties in such calculations, producing erroneous estimates that may result in uneconomical completions. Consequently, many Brushy Canyon completion decisions involve the acquisition and analysis of more expensive of core information to help reduce such errors and to provide an acceptable indicator of the presence of oil. We have developed a new method, to reduce the risk of Brushy Canyon completions, involving a two-step process. The first step is to correlate wire-line logs to the bulk volume oil (Φ*So), obtained from core analysis and the second is to correlate Φ*So based statistical parameters with well performance.

These correlations were achieved using two sequential Neural Networks. The first Network was trained and tested using four inputs, the density and neutron porosity along with the shallow and deep resistivity logs, to correlate with the bulk volume oil (Φ*So) obtained from core analysis. The resulting network was used to estimate Φ*So for 34 Brushy Canyon wells that were not a part of the training data set. The second network was trained and tested using statistical data; sum, average and standard deviation of the estimated bulk volume oil, to correlate with the average monthly production for the first year the well produced. A cross plot of the estimated production versus the actual production of these wells was then used to evaluate the commercial viability of new wells or reentry completions in the Brushy Canyon.

This new method provides a simple and economical alternative to the more expensive coring and analysis. In addition, it could be used to evaluate behind-pipe recompletion opportunities in the Brushy Canyon interval of the Delaware Sands in the Permian Basin.

Introduction

The Delaware Mountain Group in the Delaware basin of New Mexico consists of a thick (4500 ft) sandstone and siltstone interval with 95% of the sandstone medium to fine-grained.[1] Porosity and permeability in the productive interval range from 12-25% and 1-5 md respectively.[1] Typically the clay content is less than 5%.[1] Stratigraphic divisions are uncertain,[1] but the top of the Lower Brushy Canyon is regionally identified by a kick in the gamma ray and the accompanying resistivity logs. A standard suite of logs includes gamma ray, neutron and density porosity, plus shallow and deep resistivity. Generally the density log produces the best estimate of porosity, but calculating water saturation is problematic.[1] Others[2,3] have reported similar problems in estimating water saturation in thin-bed, low resistivity formations.

Around 1990 improved sidewall coring technology resulted in the recovery of samples for laboratory analyses and the ability to accurately record sample depth. Reference 2 recognized the thin-bed, low resistivity problem and developed a procedure to calibrate the available logs with the new core information. The procedure follows:

"*using the full-core analysis to calibrate log calculations, a procedure was developed to identify the zones that are oil-productive. The procedure is based on the premise that zones with residual oil saturation have a high probability of being productive and zones with no residual oil saturation have a low probability of being productive. By calibrating the Micro Lateral Log to calculate a residual oil saturation value for each one-half foot interval from the digitized log, potential pay zones were identified. By applying porosity correction transforms, setting gamma ray and porosity limits, and calibration of resistivity values, a more accurate determination of the productive intervals was made.*"

Reference 3 recommends accounting for the difference in scale between the point measurements of the core analysis and the lower resolution log measurements by including the location of each plug and adjusting the log parameters, "m" and "n" in log interpretations. Both Refs. 2 and 3 are methods of calibrating well-known equations with core information.

A typical suite of logs through the Lower Brushy Canyon is seen in Fig. 1. The perforations visually correlate to relatively dirty sandstones with gamma ray values of 40 to 50 units, low deep resistivity values with pessimistic water saturations, and cross-plot porosity greater than 12%. In conjunction with wireline logs, completed zones correlate to mudlog shows, drilling breaks and sidewall core shows. A whole core was collected from Nash 23 and the analyses are available to compare with the log estimates.[4] The density log porosity (average over 2 ft) is compared to the point (0.5 ft) measurement shown in Fig. 2. Notice that the log measurement overestimates the core porosity. The same data is expressed as a cross plot in Fig. 3 where the extent of the error is especially evident at low values of core porosity

The density log porosity measurements were used in Archie's equation to estimate water saturation. The bottom-hole temperature corrected Rw was 0.028 ohm-meters and a 0.9 sandstone constant was used to calculate Sw.

$$Sw = c\sqrt{Rw/Rt}\,/\,\Phi$$

A cross-plot is used to compare the core measured water saturations to the log estimates in Fig. 4. Notice that at low values of log-derived water saturations, the core saturations are very high. Lower Brushy Canyon completions generally produce water with the oil, indicating that water saturations exceed irreducible values.

If the correlation between core residual oil measurements and log-derived values were better than that seen in Fig. 5, the BVO (ϕ x S_o) plot would be a useful tool. The problems associated with estimating water saturation using log information and well-known equations are summarized in Fig. 6. The circles are 70 wells where a completion was attempted in the Brushy Canyon.

Tuning the well-understood log parameters with core information is defined as a forward modeling method. Including additional information such as the gamma ray log response as done in Ref. 2 improves the forward models. Accepting the core information as "truth" and developing equations to fit the log information to the core data is an inverse problem.

Procedure

This procedure is built on the idea that the inclusion of core oil saturation values in log analyses improves the interpretation. It also assumes that statistical parameters can be correlated to production. This poses an inverse problem of correlating between the various logs, the core measured bulk oil and production, which can be solved by developing multivariate equations such as those resulting from neural networks.

The correlations were achieved using two sequential networks. The network was used to correlate the log data with the bulk volume oil and the second to correlate statistical data based on the estimated bulk volume oil with the average monthly production for the first year of production. A destructive design methodology was used to obtain the optimum network architectures. The ratio of the input records to the number of network tie lines had to be kept below 2:1 to avoid over training of the networks.

The two porosity logs and density logs served as inputs to the first network. The reason being a standard suite of logs include the porosity and density logs. Also because the neutron log is affected by the presence of hydrocarbon, the density log gives a good estimate of the porosity and the shallow and deep resistivity logs provide information on saturations within the formation. A total of 214 output data (obtained form cores), averaged over 2-ft intervals, was used to train and test the neural network. Correlations were developed between the four log inputs and the core measured bulk volume oil defined as :

$$(BVO)_{core} = \phi \times S_o$$

This neural network was highly complex. It had an input layer consisting of 4 nodes, an output layer consisting of a single node and four hidden layers with 6, 4, 5, 2 nodes respectively. This network trained to a correlation of 85% with 100% of the available data. The finished network was subjected to a validation testing process with 80% of the available data.

The second network was trained and tested using the sum, average and standard deviation of the bulk volume oil from 34 wells. This network was less complex consisting of an input layer with 3 nodes, an output layer with one node and one hidden layer with 4 nodes and trained to 86%. The architectures are shown in Fig. 7 and Fig. 8. The training results, of the two networks, are shown graphically in Fig. 9 and Fig. 10.

Discussion

The correlations developed were applied to 16 Brushy Canyon wells in the Nash Draw field to estimate the bulk volume oil. The main goal of this process was to validate the efficiency of the trained network to make predictions on other wells. These wells also had core information that was used to compare the results. Some of the results are shown in Fig. 11 and Fig. 12.

Having validated the network, it was used to estimate the bulk volume oil in 34 Brushy Canyon wells. The average, sum and standard deviation of the estimated BVO values were used to train the second network. This trained network was used to directly estimate the average production for Brushy Canyon wells as shown in Fig. 14.

Conclusions

During the past, log-derived estimates of water saturation have resulted in a number of non-commercial completions. Improvements in sidewall core technology and the development of a new forward log interpretation[2] method resulted in the inclusion of point measurements in completion decisions.

A sequential neural network was used to first correlate between logs (neutron and density porosity, shallow and deep resistivity) to the bulk volume oil measured from the cores. A second network was used to correlate the sum, average and standard deviation of the bulk volume oil log through the Lower Brushy Canyon interval to the average monthly production. These correlations could be used to evaluate recompletion opportunities in the Brushy Canyon interval of the Delaware Sands. The interval to be perforated can easily identified on the bulk volume oil log.

Acknowledgements

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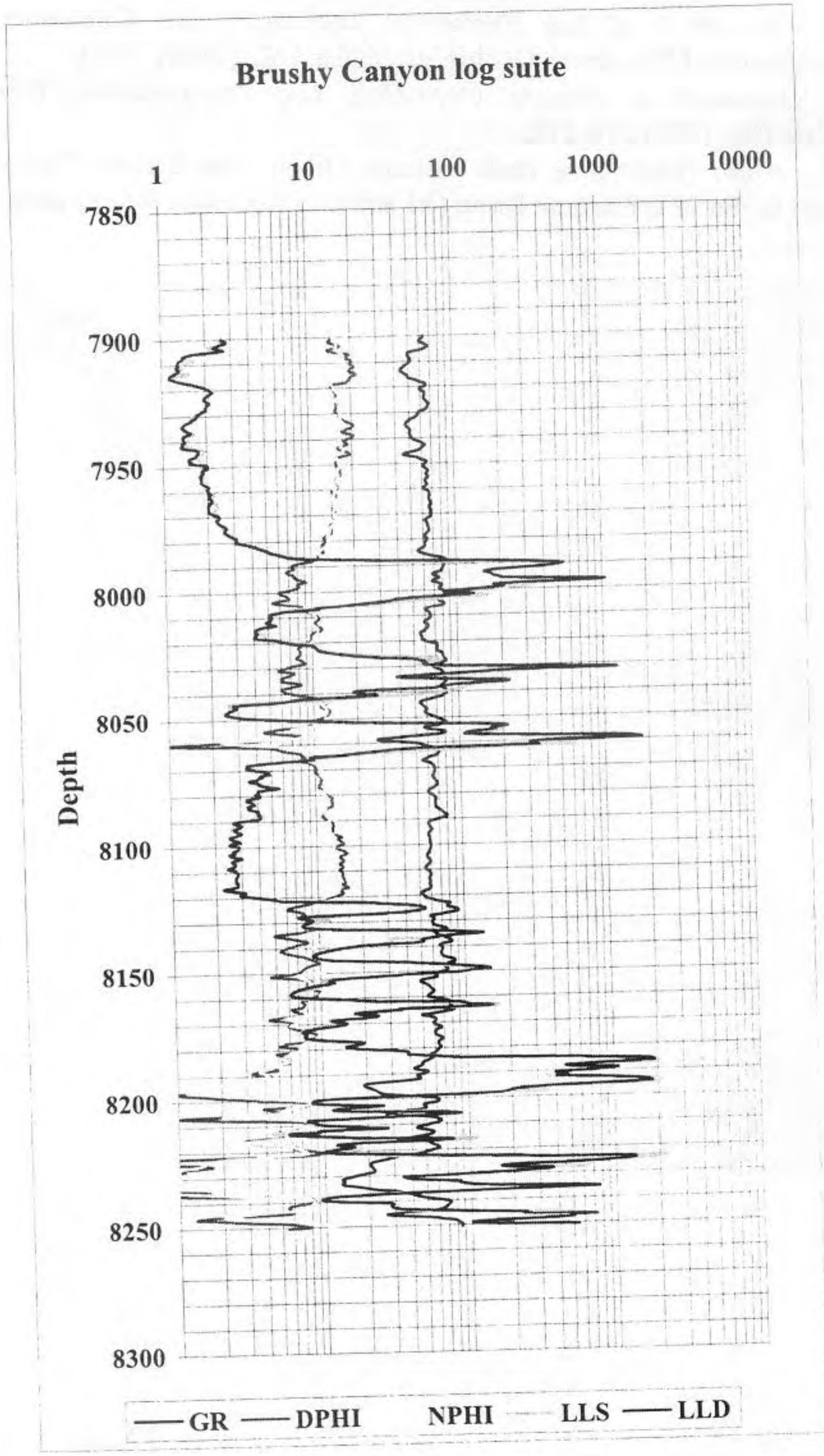

Fig. 1: Typical Lower Brushy Canyon log.

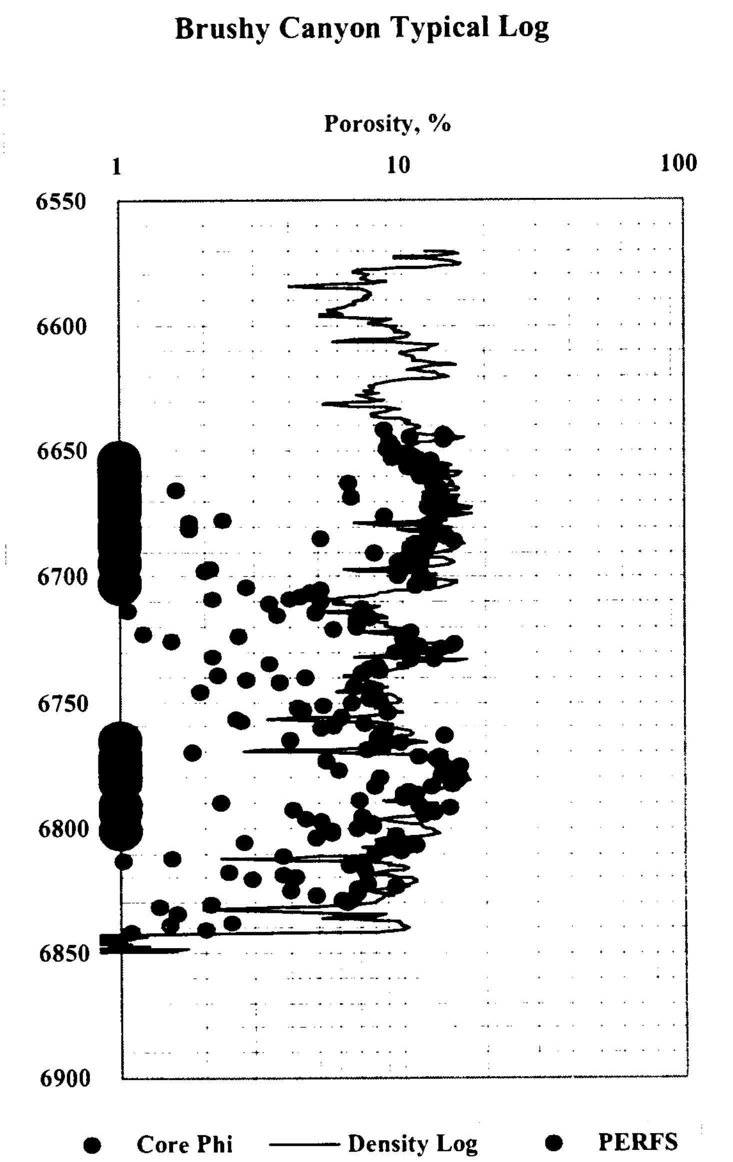

Fig. 2: Comparison of whole core porosity to log porosity

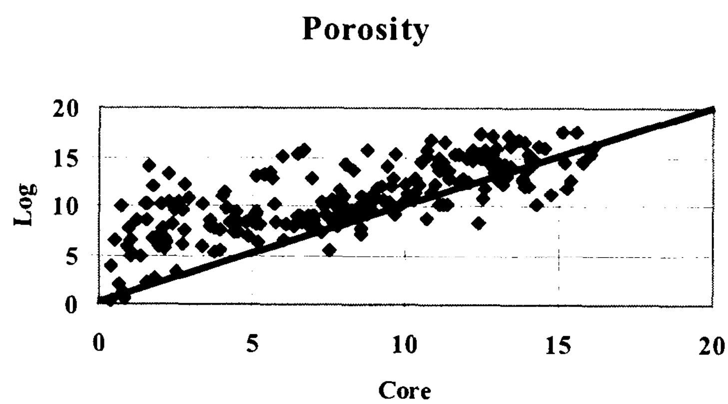

Fig. 3: Cross plot of log and core porosities

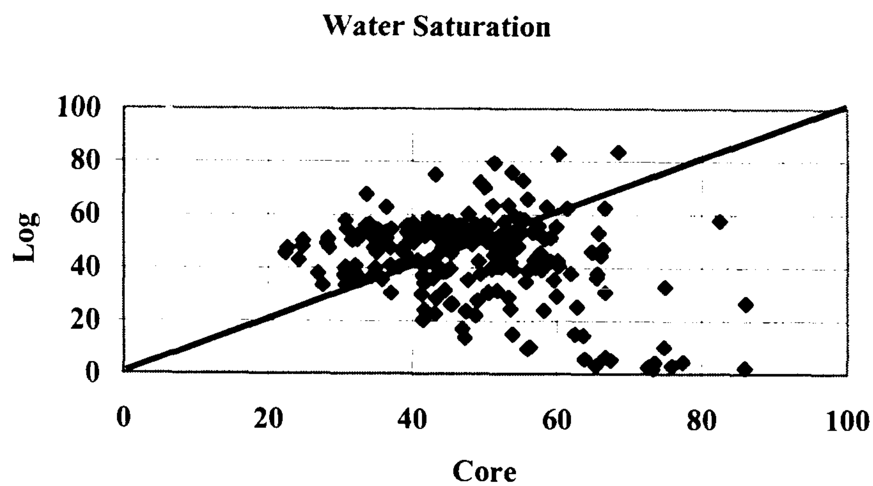

Fig. 4: Cross plot of log derived water saturation vs core measurements

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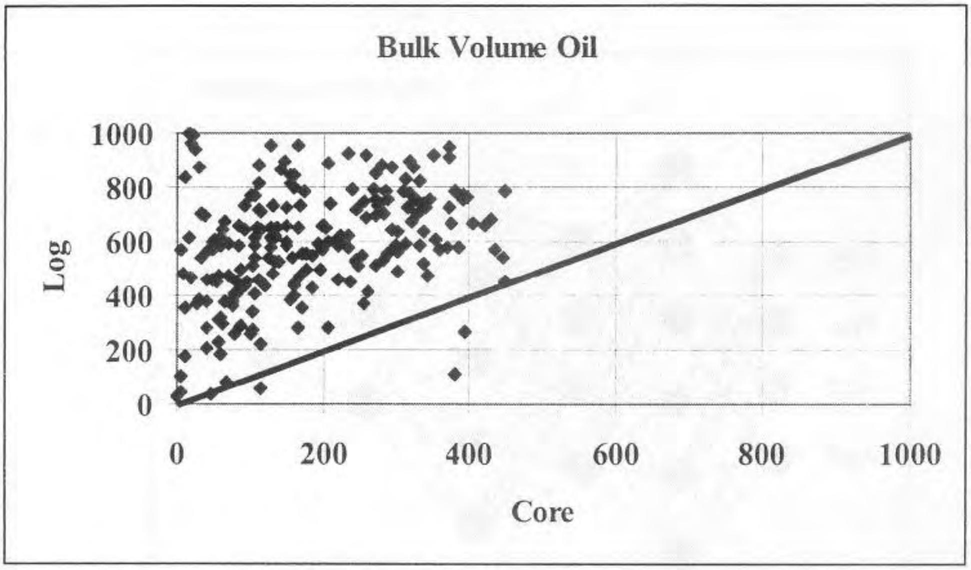

Fig. 5: Cross plot of log derived BVO vs. core measurements

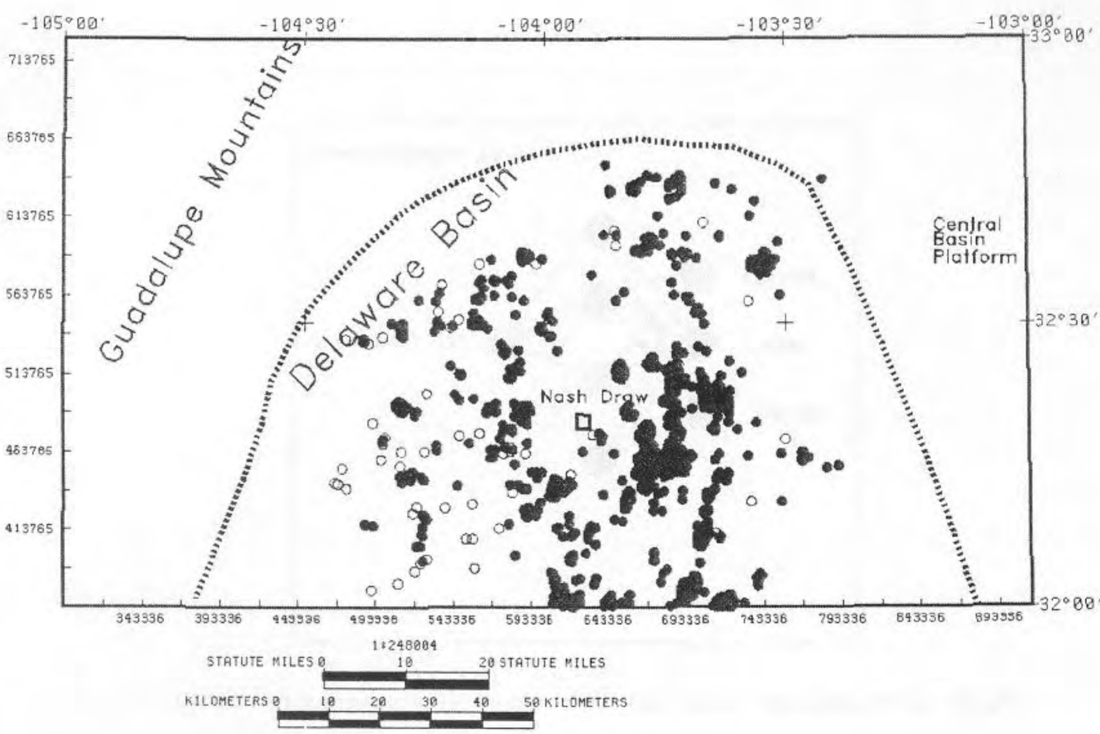

Fig. 6: Well locations map for the Brushy Canyon. Un-filled circles represent non-commercial completions

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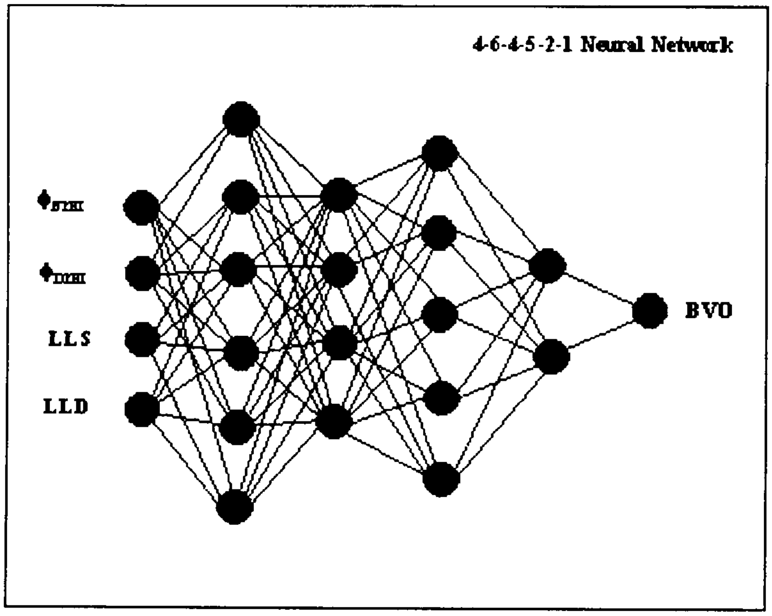

Fig. 7: Neural Network architecture used to correlate logs with core measured bulk volume oil

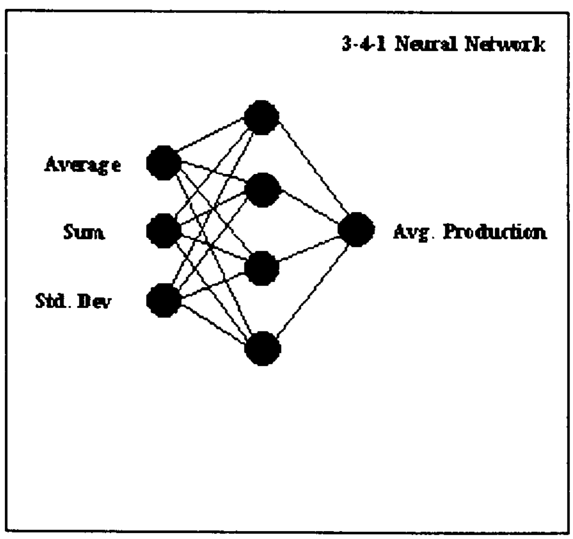

Fig. 8: Architecture used to correlate bulk volume oil with average production

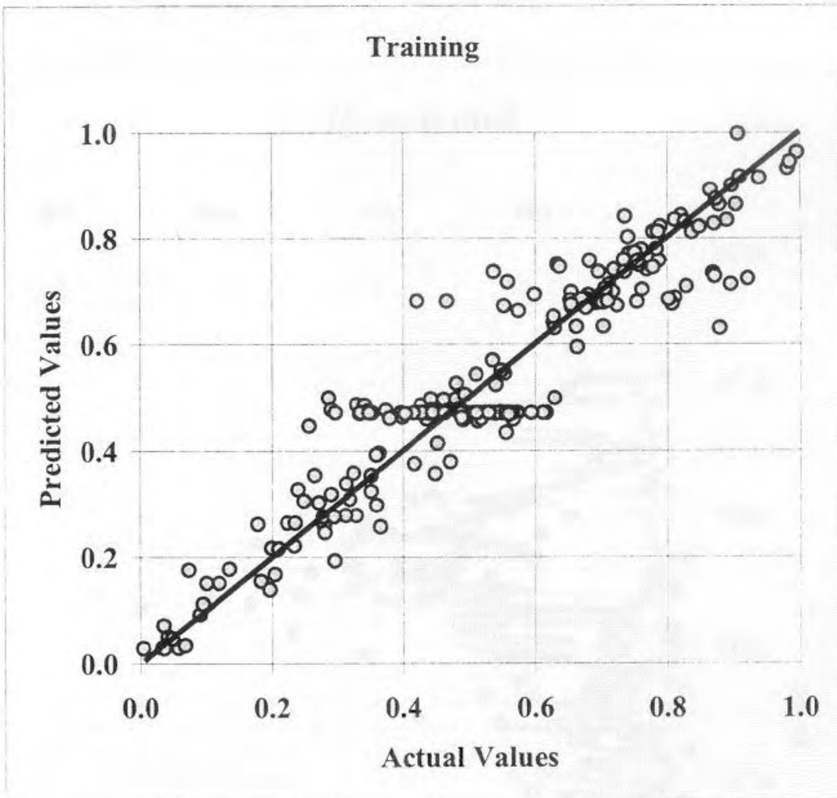

Fig. 9: Training results for network used to correlate logs with core measured bulk volume oil

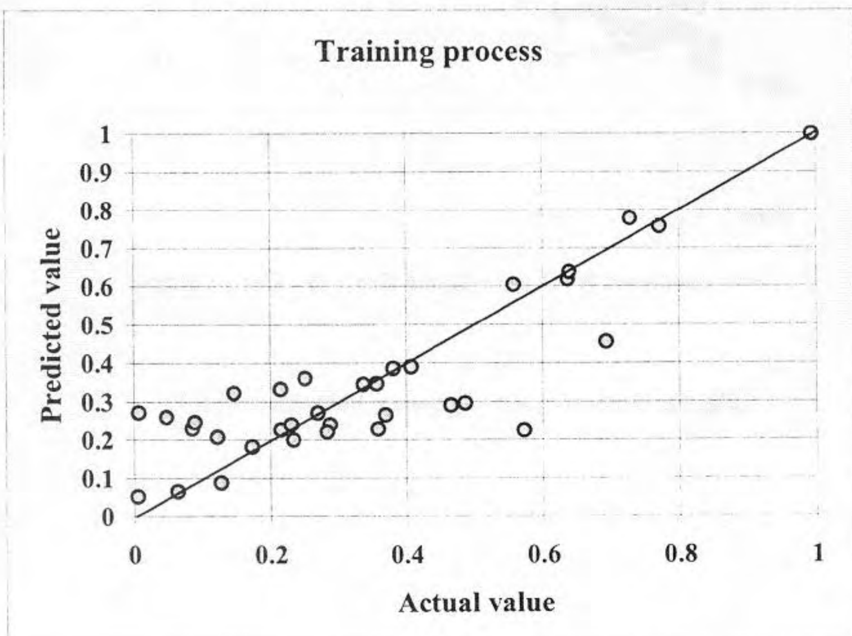

Fig. 10: Training results for network used to correlate standard deviation, average and sum of bulk volume oil with production

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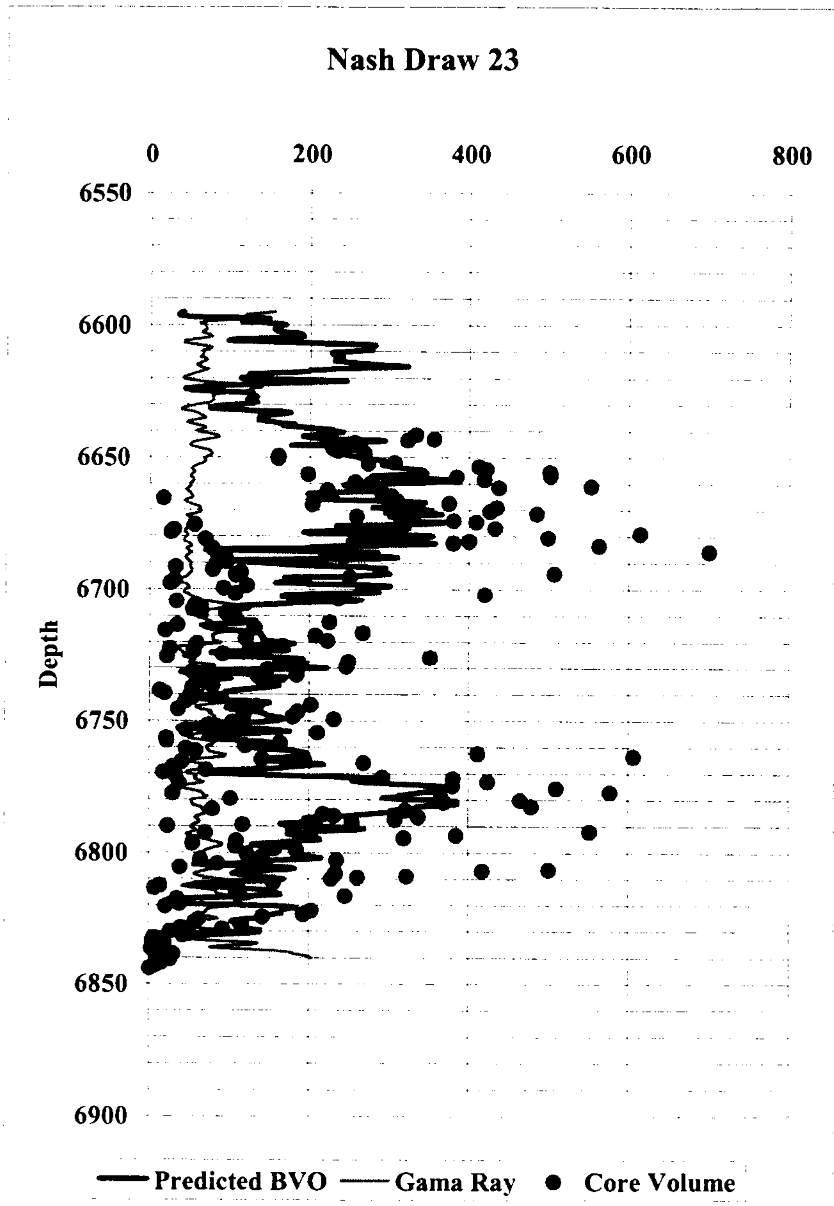

Fig. 11: Network used to generate bulk volume oil log

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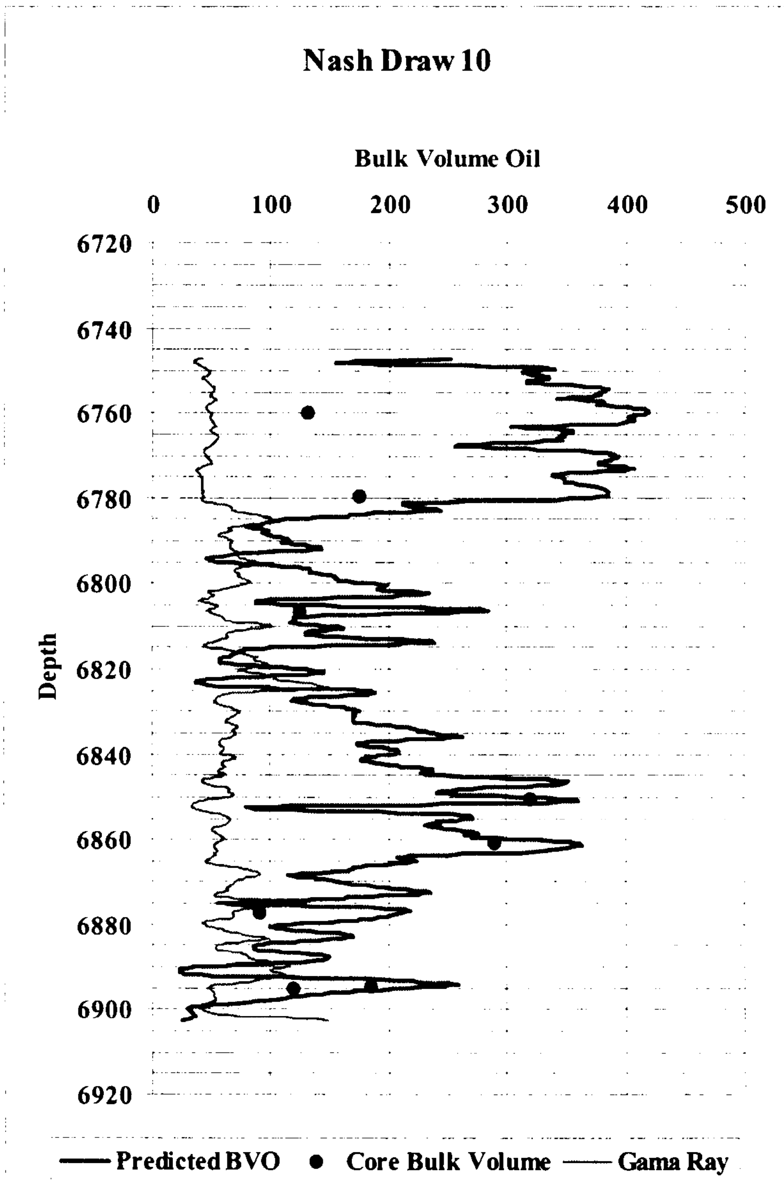

Fig. 12: Network used to generate bulk volume oil log

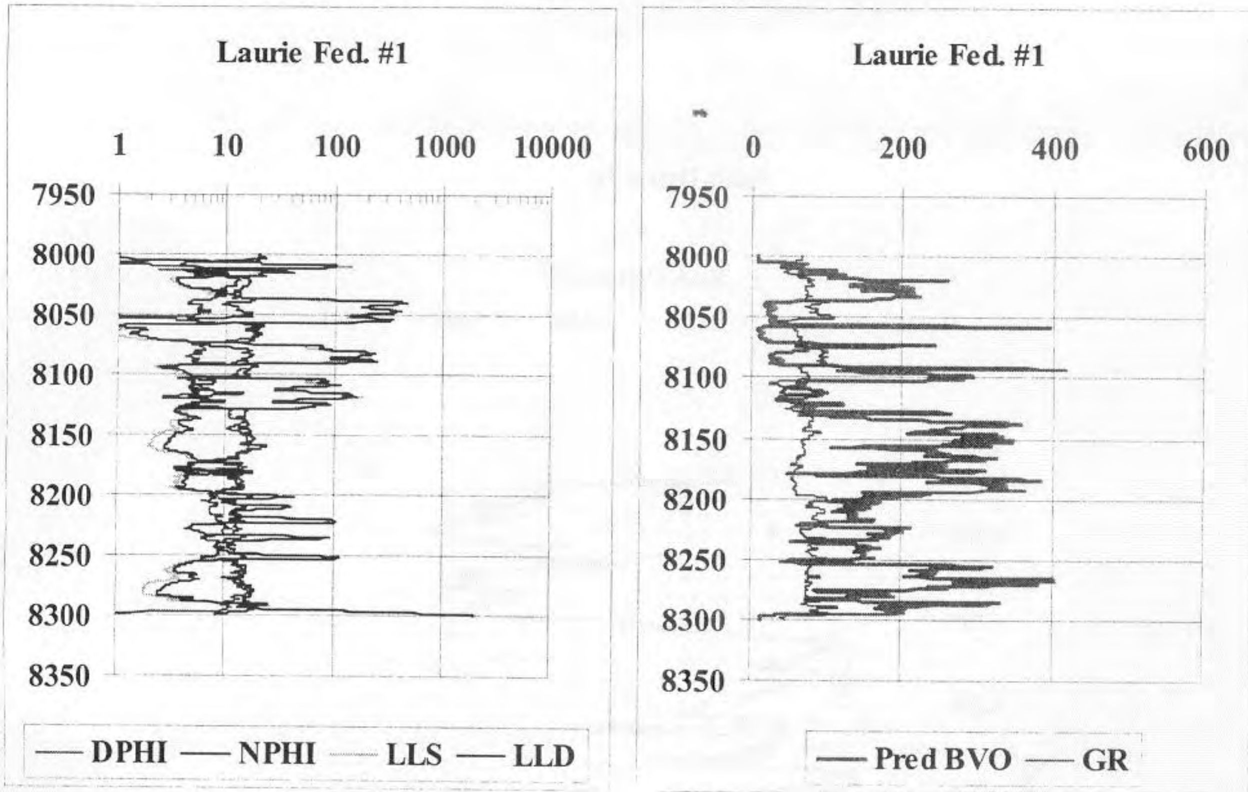

Fig. 13: Neural network developed in Fig. 7 used to generate the BVO log, shown on the right, using the porosity and resistivity logs, shown on the left, as input to the network

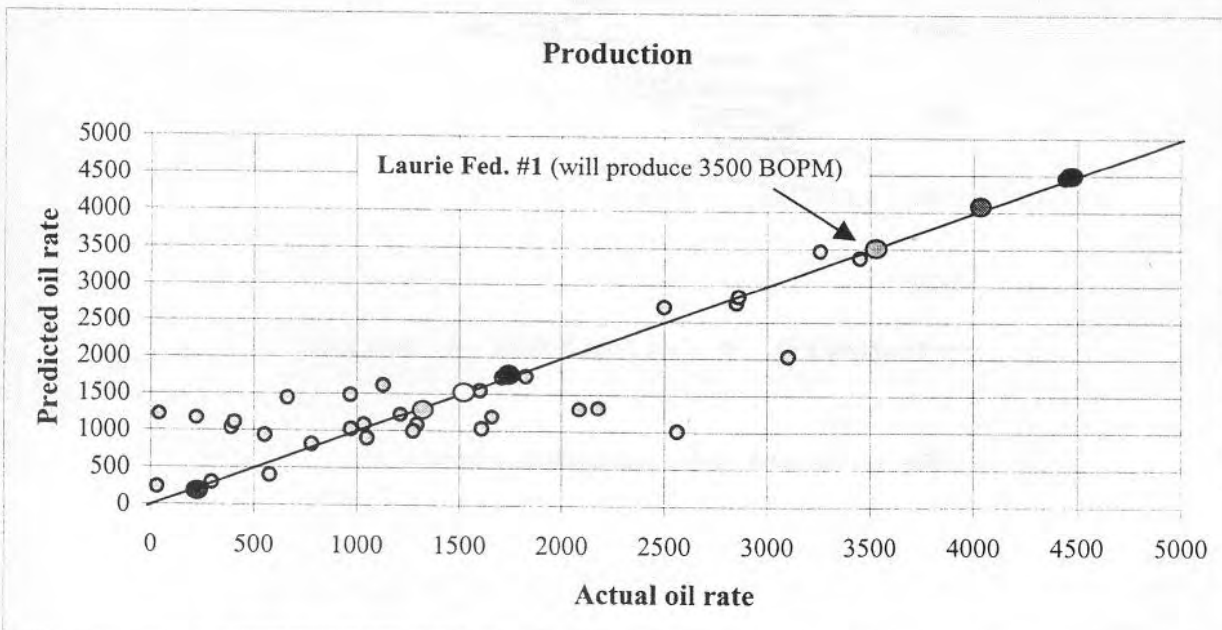

Fig. 14: Average, sum and standard deviation of bulk volume oil used to predict production using the network developed in Fig. 8