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Reducing the Cost of Field-Scale Log Analysis Using Virtual Intelligence Techniques

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Abstract

One of the costliest parts of field-scale reservoir studies is log analysis. A recent GRI project required a detailed study of a field with hundreds of wells. As part of this study all the well logs were to be analyzed by an engineer in order to identify net pay, porosity, and saturation. It soon became apparent that a considerable amount of time must be devoted to well log analysis in order to obtain consistent and high quality reservoir characteristics throughout the field. This was mainly due to the fact that logs for several wells were missing and many wells did not have the suite of logs that were necessary for analysis.

This paper presents a novel approach to reduce the cost of well log analysis while maintaining the quality of the analysis. The cost reduction is achieved by analyzing only a group of the wells in the field. Using the detailed analysis of this group of the well logs by an expert engineer, an intelligent software tool is built to learn and reproduce the analyzing capabilities of the engineer on the remaining wells.

This approach provides a means to increase the efficiency of the engineering team. It can decrease the time needed to analyze a large number of well logs while considerably reducing the project cost to the operator. It will provide means to attain well log analysis for wells that do not have all the necessary logs needed for the analysis. This is achieved by generating virtual wireline logs for these wells. Virtual intelligence techniques are used in construction of the intelligent software tool presented in this study.

Introduction

In field-scale reservoir studies that include hundreds of wells, a large percentage of the project budget is allocated for log analysis to obtain reservoir characteristics such as porosity and saturation. Log analysis in a large field-scale study can be quite labor intensive and time consuming and therefore, expensive. On the other hand many reservoir studies will suffer extensively if a proper log analysis is not performed to identify porosity and saturation. These important reservoir characteristics form the backbone of some of the most important and widely used techniques in field-scale studies such as reservoir simulation and modeling, type curve matching, and infill drilling studies. They also contribute significantly to production-based analysis, decline analysis, enhance recovery analysis, and stimulation candidate selection studies. The need for information on reservoir characteristics sometimes forces engineers to use less than desirable techniques to obtain them. This problem becomes more pronounced when the formation being studied is known to be a complex system. In such reservoirs simple interpolation techniques fail miserably in providing porosity and saturation for wells that log analysis is not being performed on. The experience has shown that statistical techniques fall short of providing meaningful correlation between the wells in these reservoirs. This is expected since most statistic-based techniques make assumptions that are not necessarily true for these reservoirs, such as pre-determined functional forms, or attempt to linearize a complex and highly non-linear problem.

This paper is an attempt to provide a solution to the field-scale log analysis problem. This study provides techniques based on virtual intelligence paradigms that increases field-scale log analysis efficiency by reducing the cost associated with the analysis without sacrificing accuracy. To clearly show the applicability of these techniques, it will be performed on a field that is known for lack of clear correlation between wells.

The field selected for this study is the Carthage field, Cotton Valley formation in East Texas. Figure 1 shows that location of Cotton Valley formation and Carthage field in East Texas. To demonstrate the feasibility of the methodology being discussed in this paper a collection of seven wells were selected from the Carthage field and the techniques were performed on these wells. Figure 2 shows the relative location of these wells. In the next section the process of developing this methodology will be discussed in detail. Moreover, this methodology can be combined with some previous developments[1-5] to produce even more powerful tools.

Methodology

As shown in Figure 2, seven wells are selected from the Carthage field in East Texas to demonstrate the feasibility of the methodology being discussed in this paper. It should be noted that the following information was available for all these seven wells: Gamma Ray, Neutron, Bulk Density and Deep Induction (Resistivity) logs as well as porosity and saturation values that were generated by an engineer using commercially available log analysis software.

The objective of this study is to simulate a series of situations that might exist in a field-scale reservoir study and build a software tool that is capable of responding efficiently to these situations. The goal of this step of the field-scale study is to map, with the highest resolution possible, and as accurately as possible, the porosity and the saturation distribution of the reservoir. The problem being faced is that we do not have a consistent suite of logs for all of the wells in the study. In order to complete the task using conventional methods flawlessly, we need a complete suite of logs (including gamma ray, neutron density, bulk density, and deep induction) for all the wells in the field. Several possible problems may arise:

- One or more of the wells lack at least one of the logs.
- One or more of the wells lack two of

the logs.

- One or more of the wells lack three of the logs.
- One or more of the wells have no logs.

The major problem with conventional approaches is that they will not work if any of the above situations are encountered. They will become unusable as soon as one of the components of their input is missing. In order to keep using the tools based on such approaches, the engineer is forced to do one of the two things. Either to abandon the analysis for that particular well (which happens most of the time) or use simple interpolation or guess work to come up with the missing input in order to get an answer from the conventional software tools. Following this method gives rise to the famous "garbage in, garbage out" phenomenon. The goal is to build a software tool that can respond to situations of missing input logs with reasonable accuracy. At this point it needs to be mentioned that what is being presented in this paper is part of an ongoing project and the authors consider the results to be of temporary in nature. We are modifying some of the algorithms and using more sophisticated techniques to enhance the outcomes being presented in this paper.

In order to accomplish the above objectives the wells in the study are divided in to two groups. Group one consisted of wells T1, T2, T3 and T4 (refer to Figure 2). We assume that these wells have complete log suites and an expert engineer, using commercially available software, has analyzed them and produced porosity and saturation logs. This group of wells is used to develop the software tool by training a series of artificial neural networks. The second group of wells is used to verify the software's accuracy. This group consisted of three wells, V1, V2 and V3. In our simulation we consider that these wells have one, two, or three missing logs, but we would like to analyze them as accurately as those wells with the complete suite of logs. Please note that information from group two wells was not utilized in development of the software tool and is only used to verify the accuracy of the tool.

An important note should be mentioned at this point. The techniques used in this study are capable of accurately generating porosity and saturation given the wireline logs such as gamma ray, neutron, bulk density and resistivity logs. There are many commercial software tools that use a complete suite of wireline logs and generate porosity and saturation routinely. Furthermore, one can easily develop her/his own spreadsheet using well-established functional relationships that can be found in many petroleum engineering textbooks to accomplish this task. What makes the techniques being introduced here novel, is the capability of generating synthetic well logs in cases where such logs are not available and where the use of conventional log analysis software would be impractical.

Figure 3 is the flow chart of the process used to develop the techniques presented in this paper. It shows that using the Gamma Ray log of a well one can generate porosity and saturation logs. In this flow chart, anytime a specific log is available for a well it can be used to enhance the accuracy of the porosity and saturation calculations. While conventional approaches and commercial software tools need a complete suite of logs to generate their results, this process is able to provide reasonably accurate porosity and saturation logs even when one or more of the logs are missing. This is accomplished by developing synthetic or virtual wireline logs based on available data.

In this technique a suite of neural networks are trained using T1, T2, T3, and T4 wells. It is important to note that since many different scenarios are possible (in terms of which well logs may be missing), many different neural nets must be trained and tested. Once the training and testing of the neural networks are completed, it is time to test and verify the accuracy of the methodology.

Results and Discussion

In order to verify the accuracy of this methodology and the software tool several scenarios were tested. These tests were conducted for wells V1, V2 and V3. The results for the three wells were quite comparable. Figure 4 shows the porosity and saturation generated for well V1 assuming that neutron log for this well was missing. Therefore the software tool generated a virtual neutron log and substituted it in the suite of logs and then using modules 5 and 6 (Figure 3) generated the porosity and saturation logs for this well. Figure 4 shows how well the porosity and saturation neutron logs generated by our software (missing the log) compares with porosity and saturation logs generated by the commercial log analysis software. Each of the three wells V1, V2 and V3 had approximately 2,000 ft of net pay in Cotton Valley sandstone. The techniques presented here were used in each well for the entire net pay. Figures shown in this paper only present a representative fraction of the entire pay (about 400 ft) for each well. Virtual well logs as well as porosity and saturation logs for the entire pay for all three wells are available and can be provided upon request. A copy of these logs is also posted at the author's web site (http://shahab.pe.wvu.edu).

Figures 5 and 6 shows porosity and saturation logs generated by our software as compared with the commercial log analysis software for wells V2 and V3 respectively. In Figure 5, the bulk density log from well V2 and, in Figure 6, the deep induction log from well V3, were assumed missing and not used in generating the porosity and saturation logs. A virtual version of these logs were generated and used in the analysis. Please note that the entire suite of logs (gamma ray, neutron density, bulk density and deep induction) was used to generate the porosity and saturation logs with the commercial log analysis software.

In the next scenario, two of the logs were left out and the porosity and saturation logs for wells V1, V2, and V3 were generated using the remaining two logs. Figure 7 shows porosity and saturation logs for well V1 generated with our software using only gamma ray and deep induction logs in comparison with corresponding logs generated using all the logs with the commercial log analysis software. Figure 8 is a similar graph for well V2. In this figure, our intelligent software generated porosity and saturation logs using only gamma ray and bulk density logs as compared with logs generated with commercial log analysis software. In Figure 9, porosity and saturation logs generated with our software when gamma ray and neutron logs are missing is shown as compared with logs generated with commercial software for well V3.

The next scenario simulates a situation where a gamma ray log is the only log available from a well. Figure 10 shows porosity and saturation logs for well V1 versus logs generated by the commercial software. The virtual porosity and saturation logs are generated using the complete process depicted in the flow chart shown in Figure 3.

As mentioned previously, using the gamma ray log virtual neutron, virtual bulk density and virtual deep induction logs had to be generated to achieve the results shown in Figure 10. It is noteworthy that our experience confirms the widely believed notion that porosity and saturation from well to well can not be correlated in the Cotton Valley sandstone. This can be seen in Figure 11 where we attempted to generate porosity and saturation logs for well V1 using no logs and only porosity and saturation logs generated by the commercial software for wells T1, T2, T3, and T4.

The reason the saturation log in Figure 11 looks much better than the porosity log generated by the software is that porosity values were used in generating the saturation log. Comparing Figures 10 and 11 shows that "some" kind of information (gamma ray log in the case of Figure 10) above and beyond the coordinates of the well is required to produce reasonable results in complex reservoirs like the Cotton Valley.

Conclusions

Field-scale log analysis is one of the most labor intensive and costly parts of field studies. The methodology introduced in this paper, helps project managers in reducing the cost of field-scale log analysis by automating a large portion of the analysis procedure. The cost reduction is achieved by requiring analysis of a subset of the wells instead of all the wells in the field. Once a subset of the wells is analyzed, the software tool developed in this study will mimic the engineer's analysis capabilities and automatically analyzes the rest of the wells in the field. A training process for the software tool is essential, but the time and effort required for training is far less than analyzing hundreds of wells. Also by developing trained, intelligent software to perform the rest of the analysis, the company will preserve the engineer's expertise on that specific field even when personnel rearrangements takes place.

On the other hand, it was demonstrated that while conventional methods and commercial log analysis software tools break down completely in the case of missing or incomplete log suites, this methodology is capable of producing reasonably accurate porosity and saturation logs. It was demonstrated that this methodology could provide porosity and saturation for the entire well while one or several logs such as neutron, bulk density, and resistivity missing. Simple more conventional statistical analysis has shown little success in developing meaningful correlations between log responses in different wells in the Cotton Valley sandstone.

It was also mentioned that the results presented here are part of an ongoing project and it is expected that the accuracy of the porosity and saturation logs produced by this methodology be improved. New algorithms and architectures are being tested for this purpose and preliminary results show that improvements over current results are achievable.

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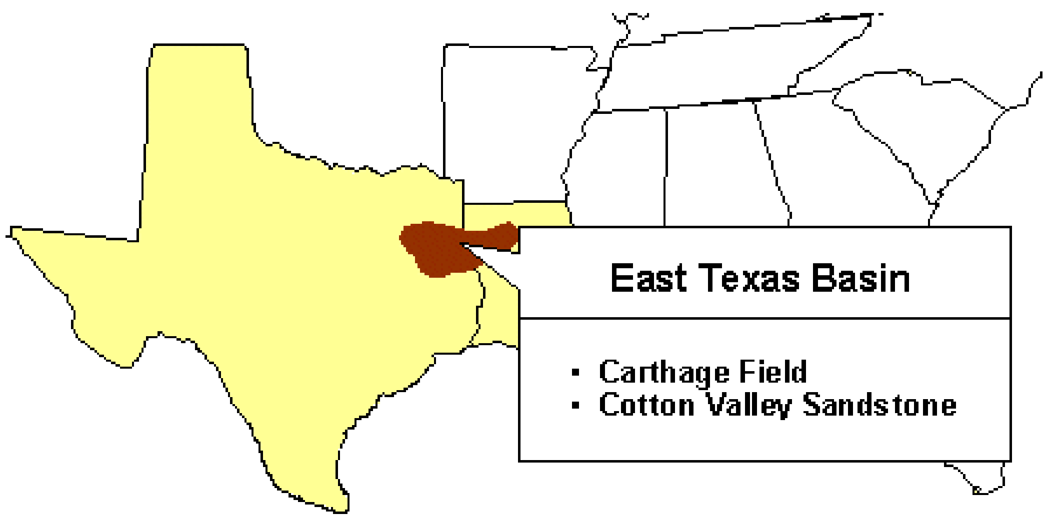

Figure 1. Cotton Valley sandstone in East Texas.

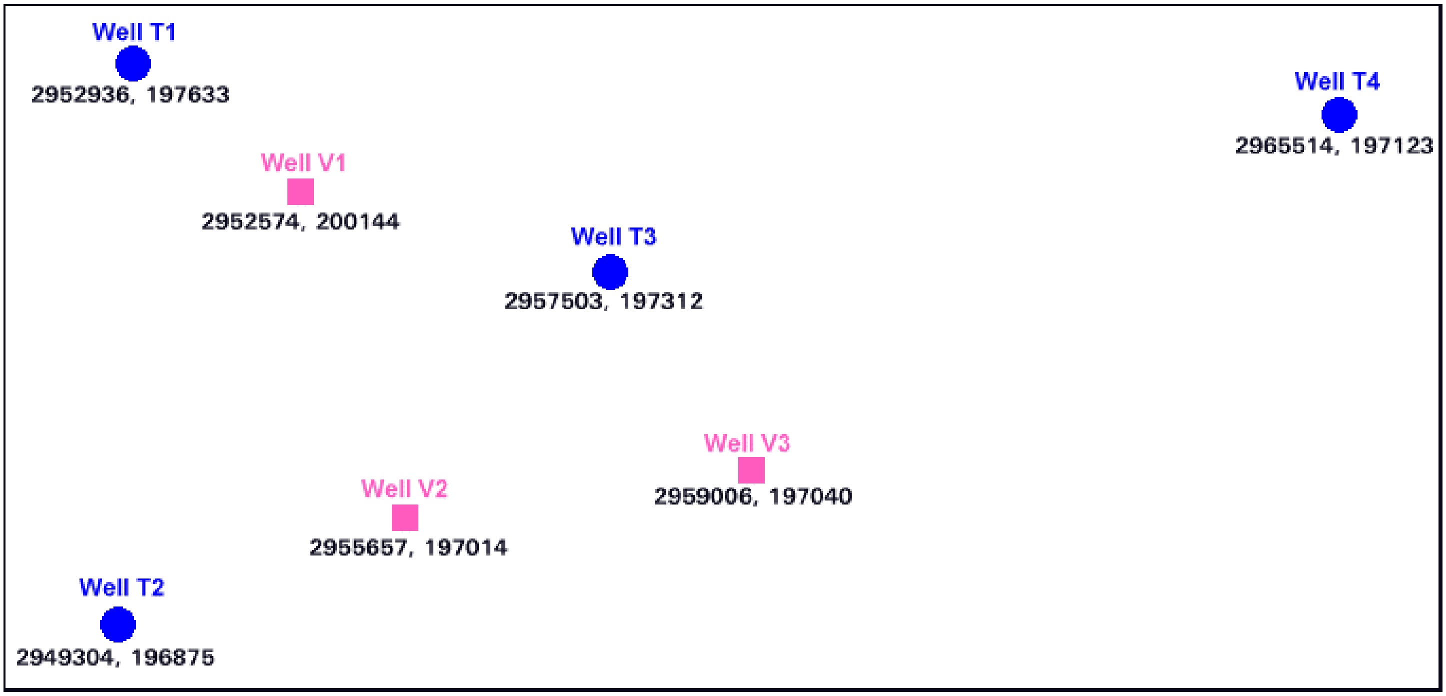

Figure 2. Relative location of wells in the study in the Carthage field Cotton Valley.

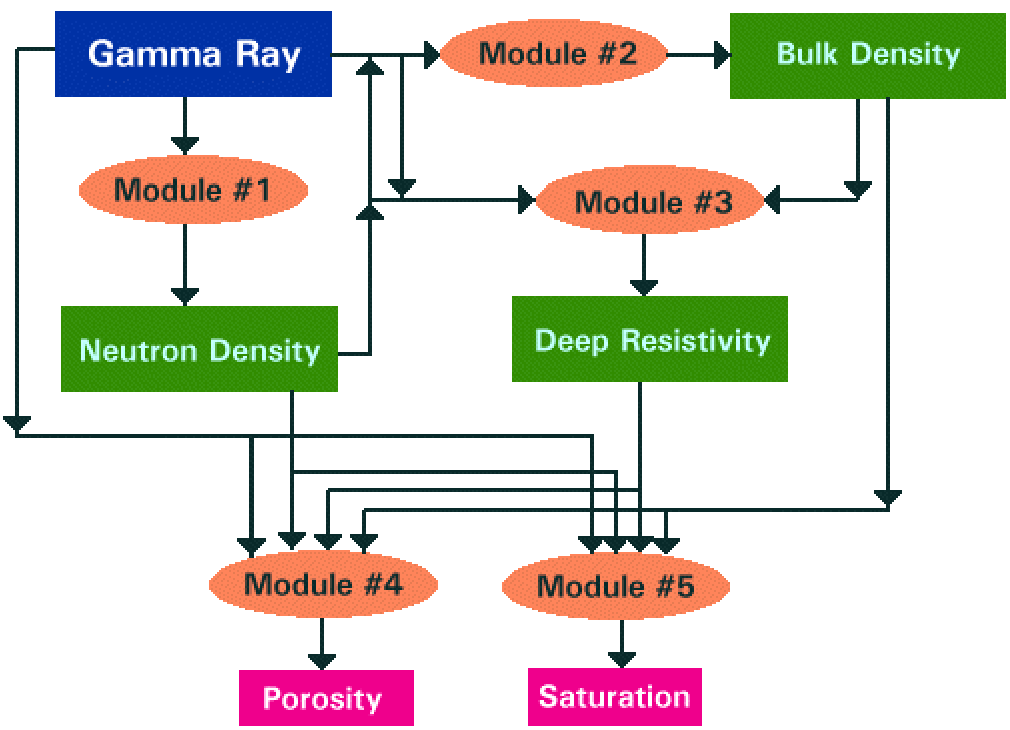

Figure 3. Flow chart of the process being introduced.

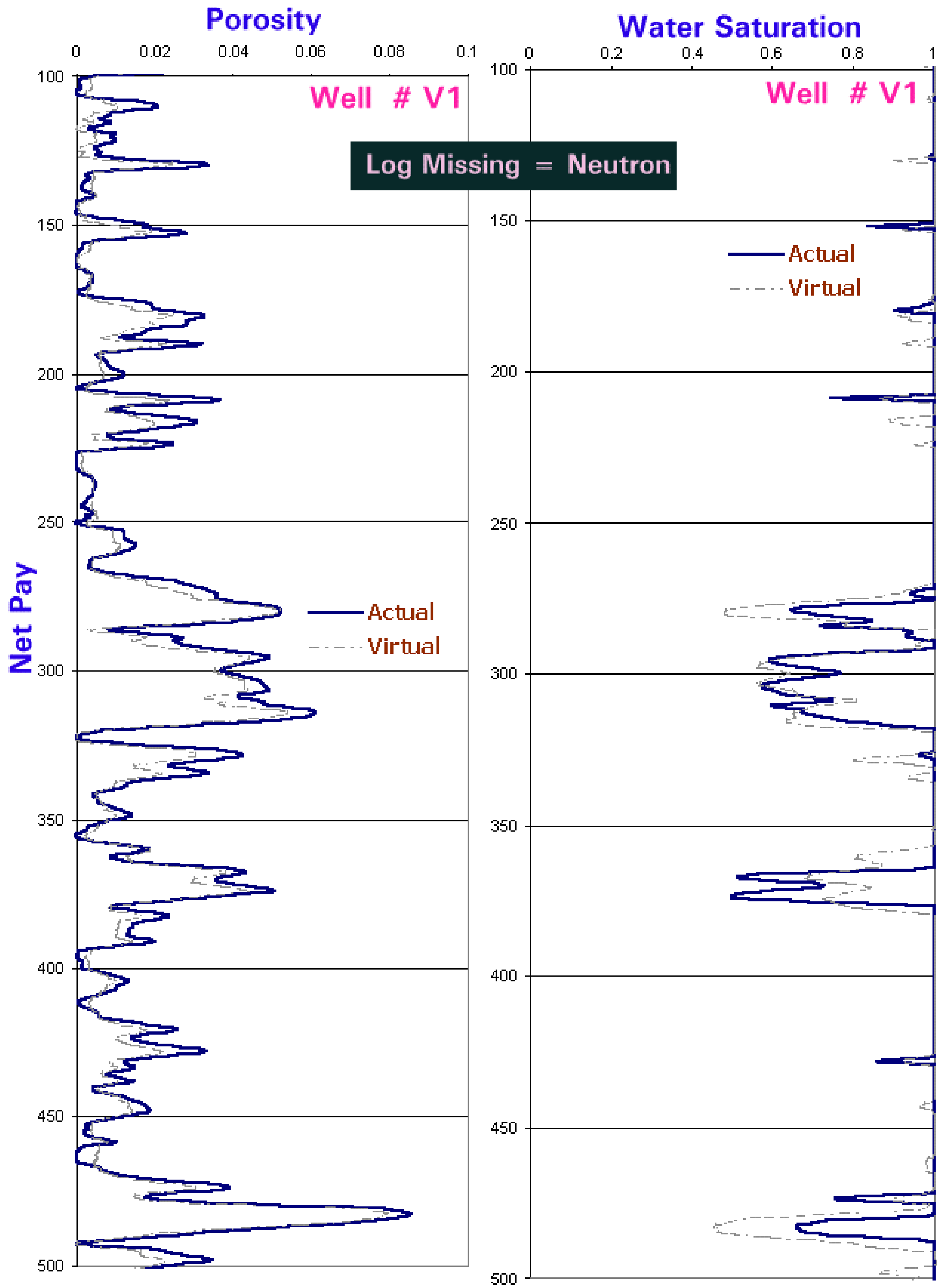

Figure 4. Porosity and saturation of well #V1 when neutron log is missing.

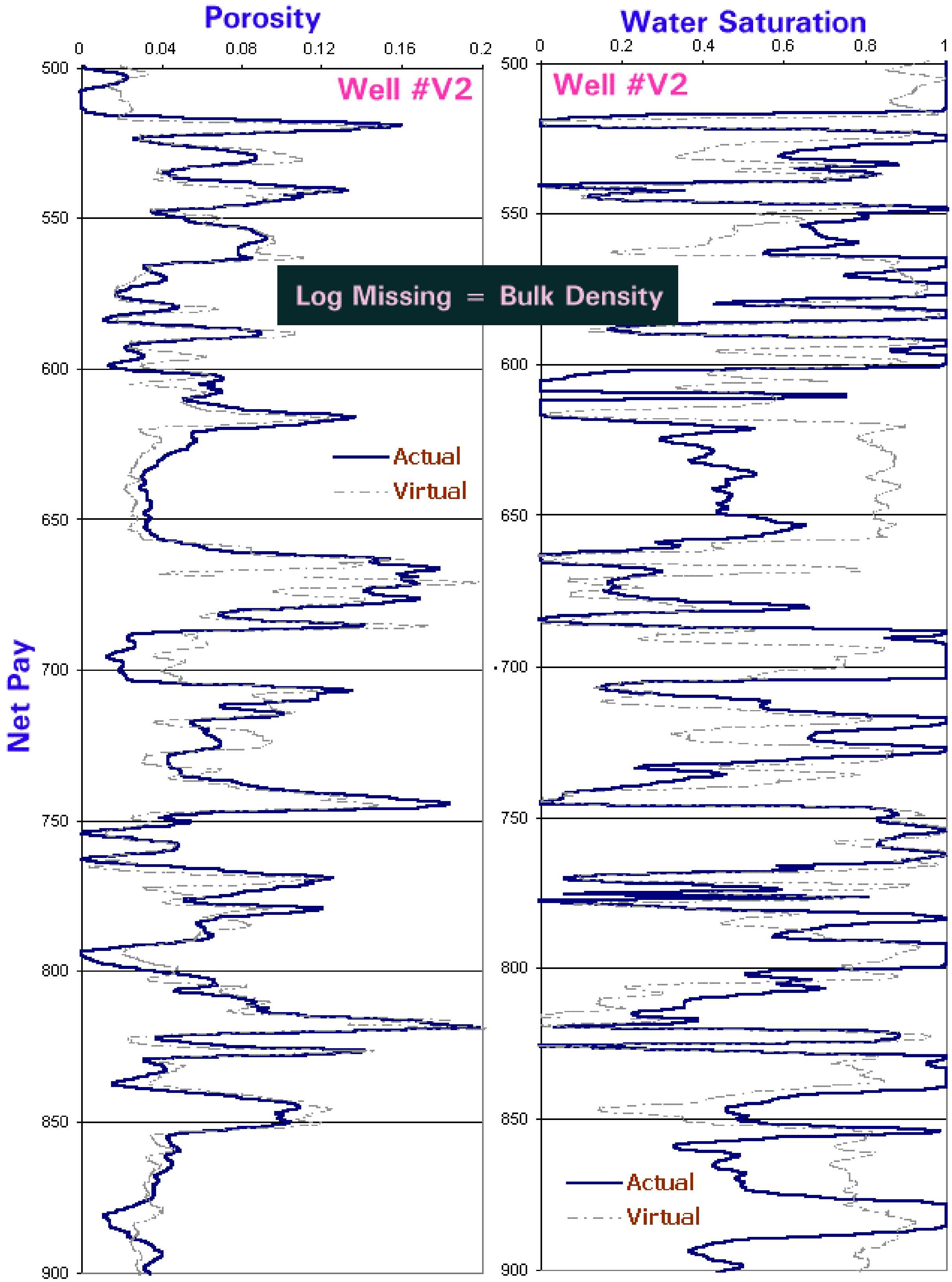

Figure 5. Porosity and saturation of well #V2 when bulk density log is missing.

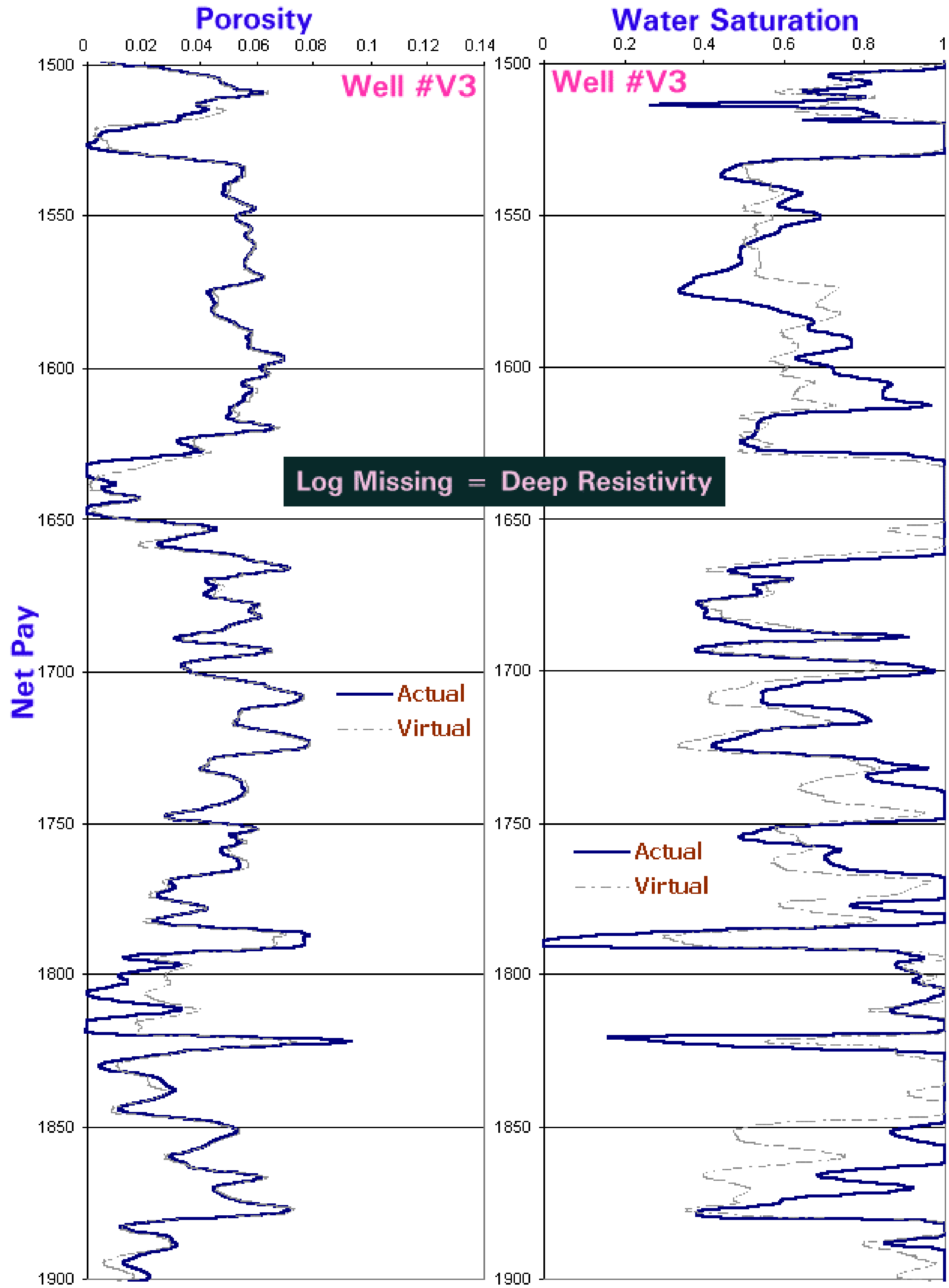

Figure 6. Porosity and saturation of well #V3 when resistivity log is missing.

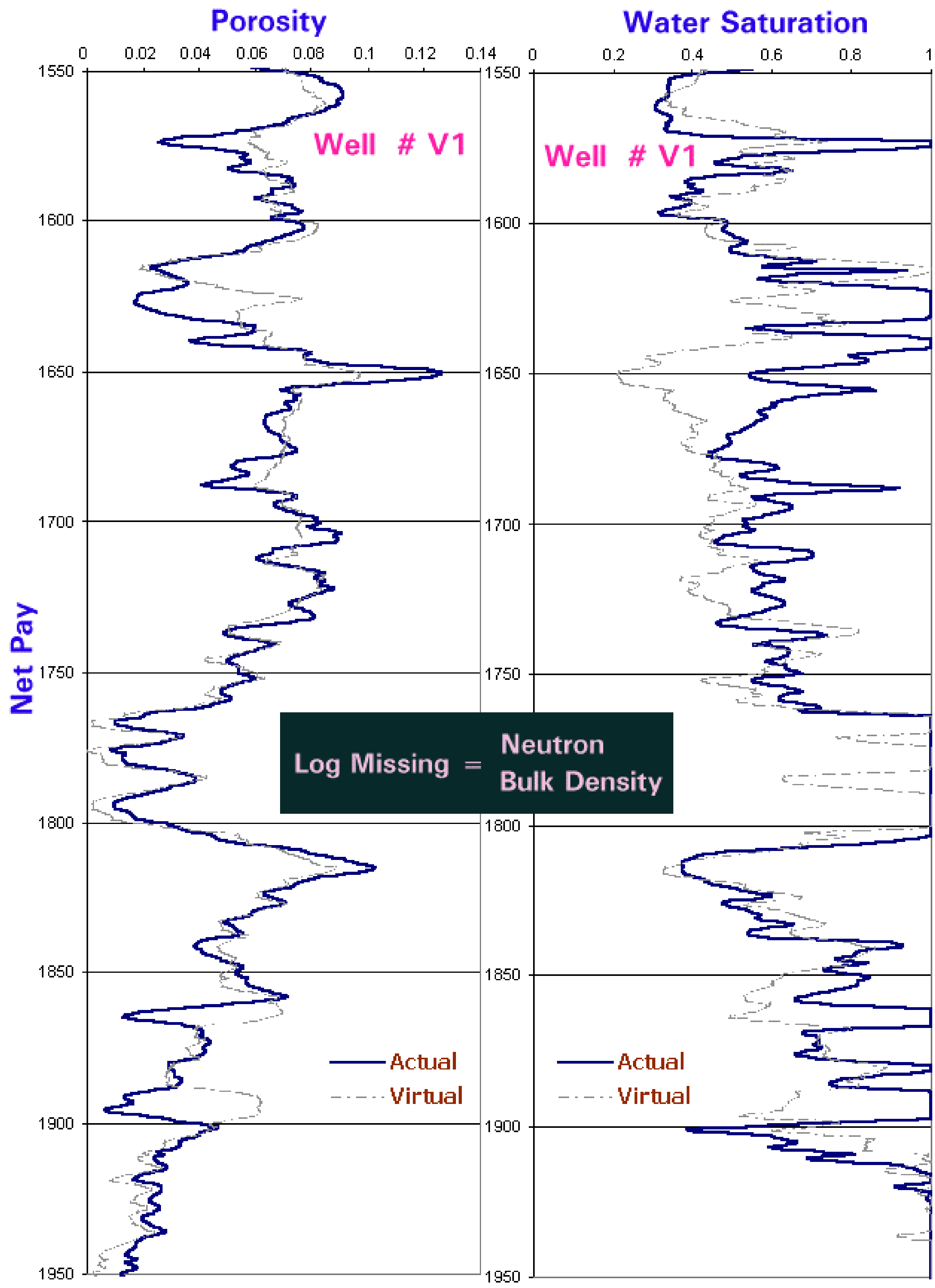

Figure 7. Porosity and saturation of well #V1 when neutron and bulk density logs are missing.

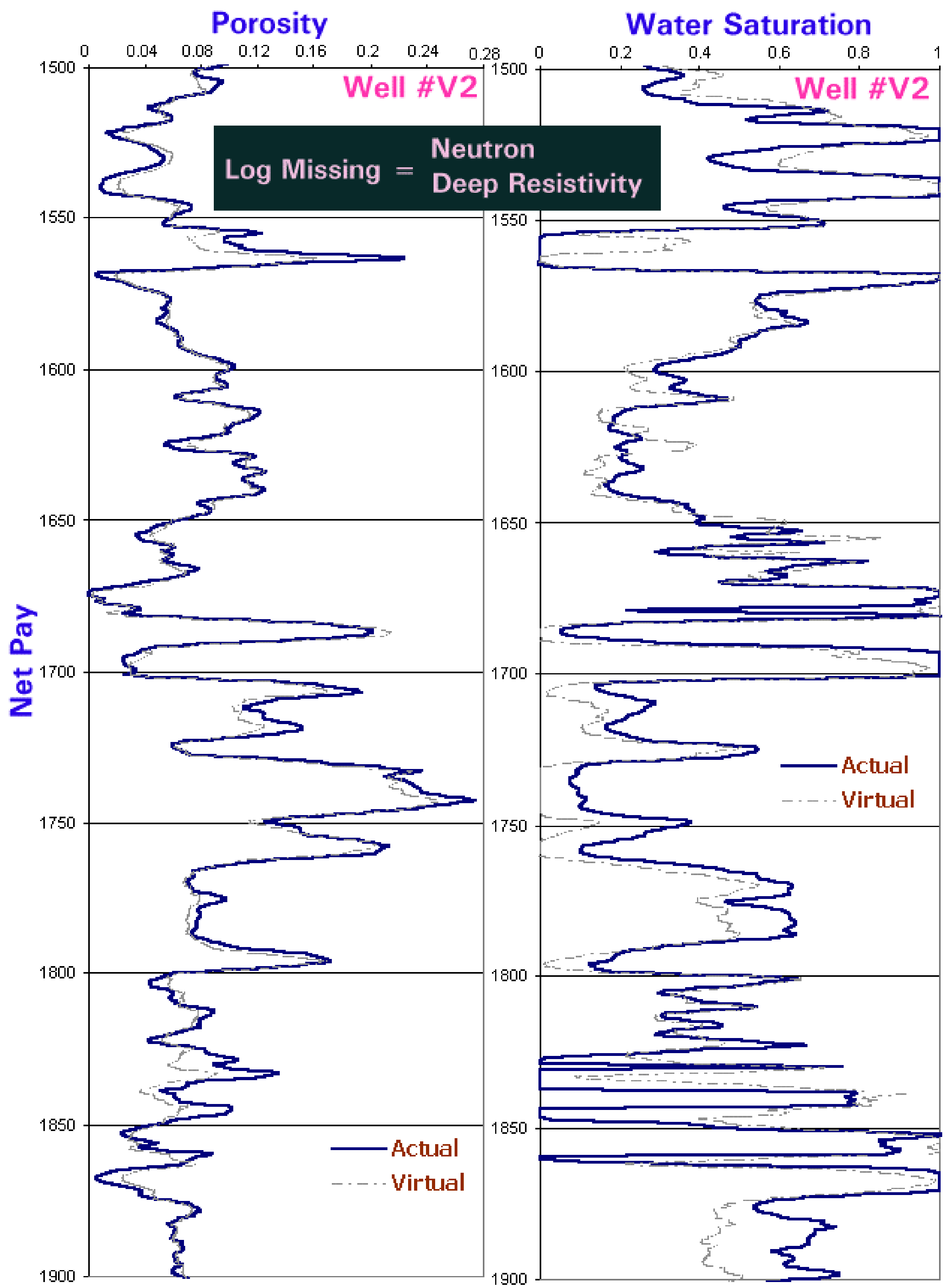

Figure 8. Porosity and saturation of well #V2 when neutron and resistivity logs are missing.

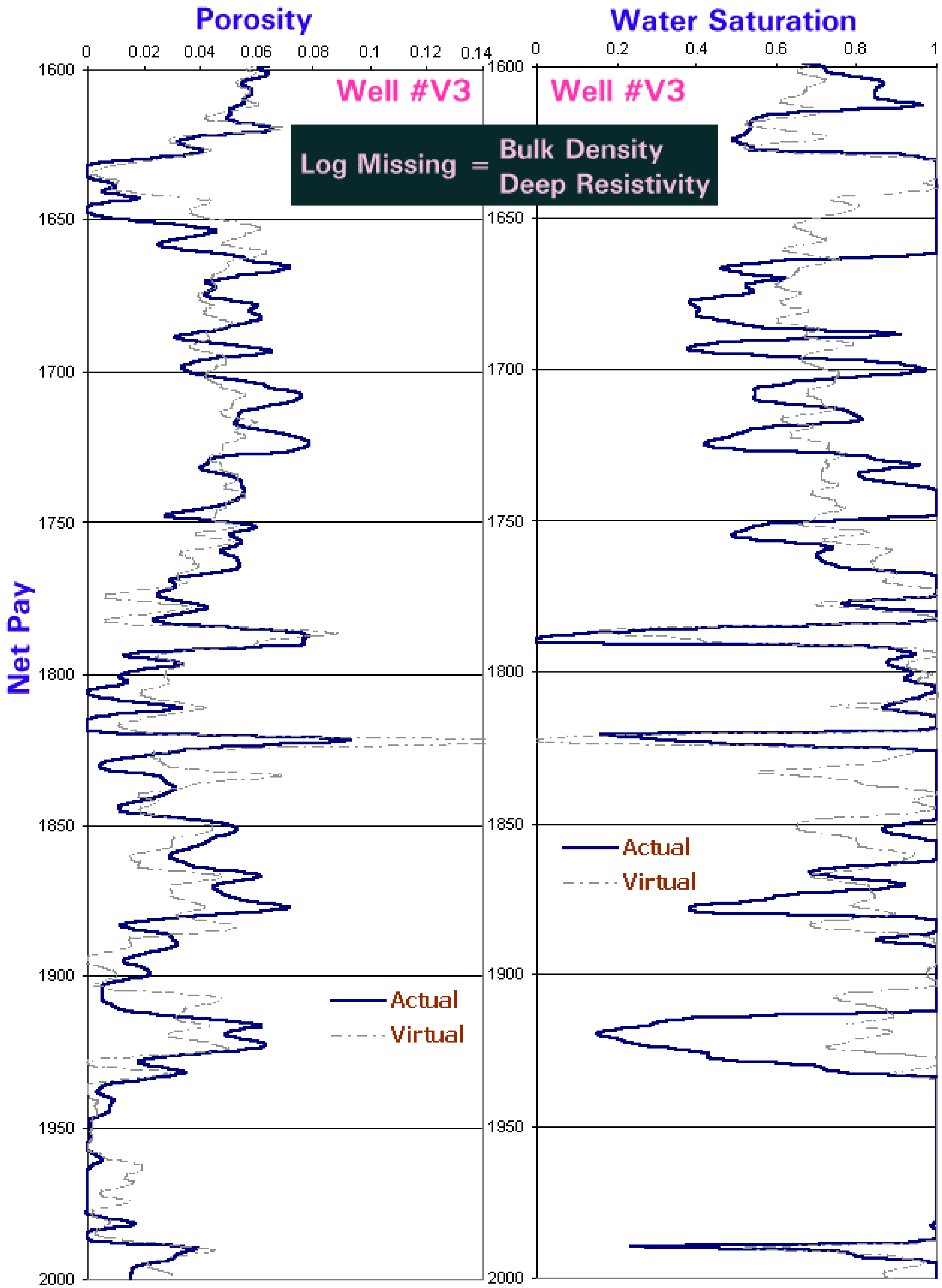

Figure 9. Porosity and saturation of well #V3 when bulk density and resistivity logs are missing.

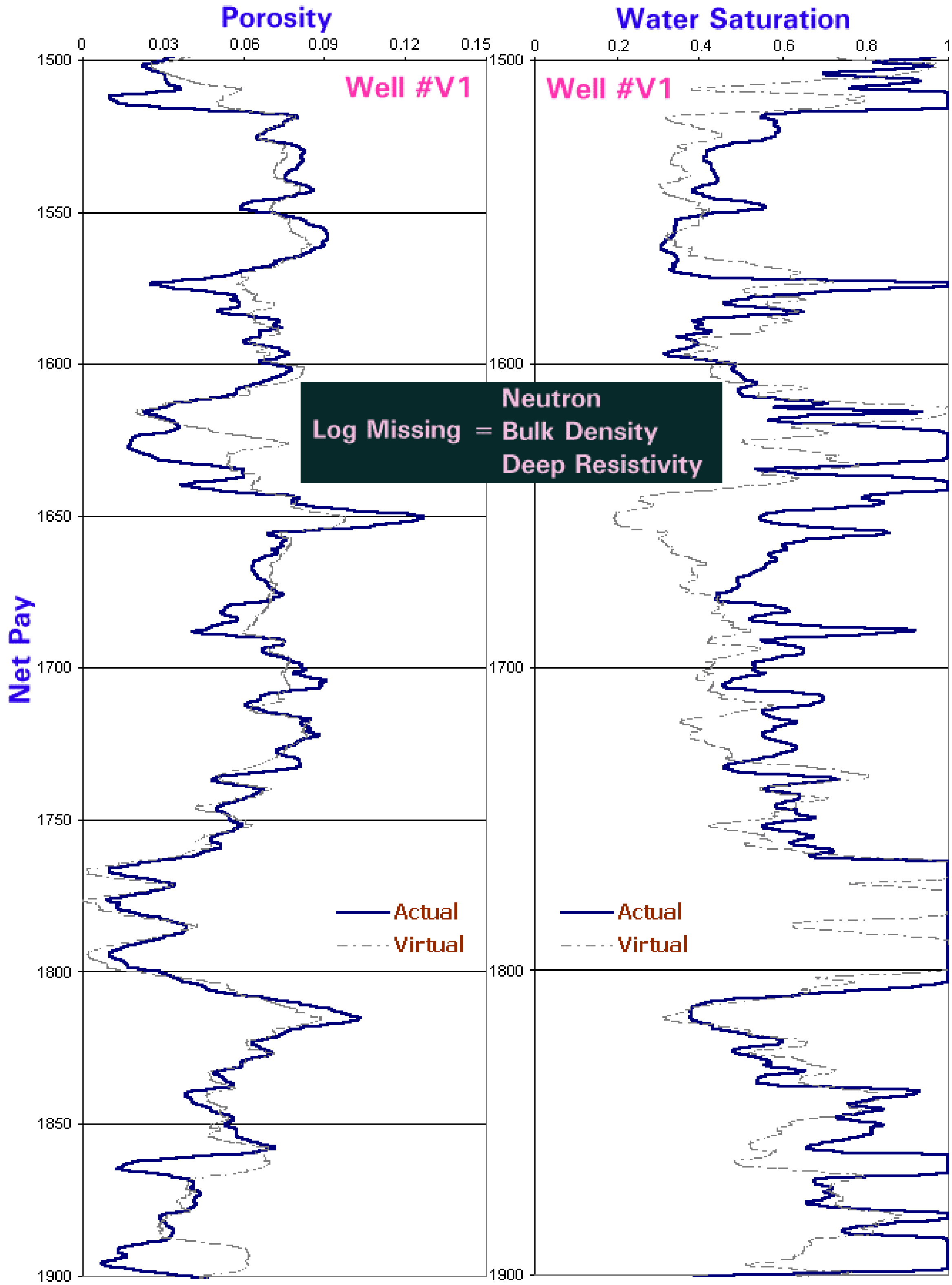

Figure 10. Porosity and saturation of well #V1 when neutron, bulk density and resistivity logs are missing.

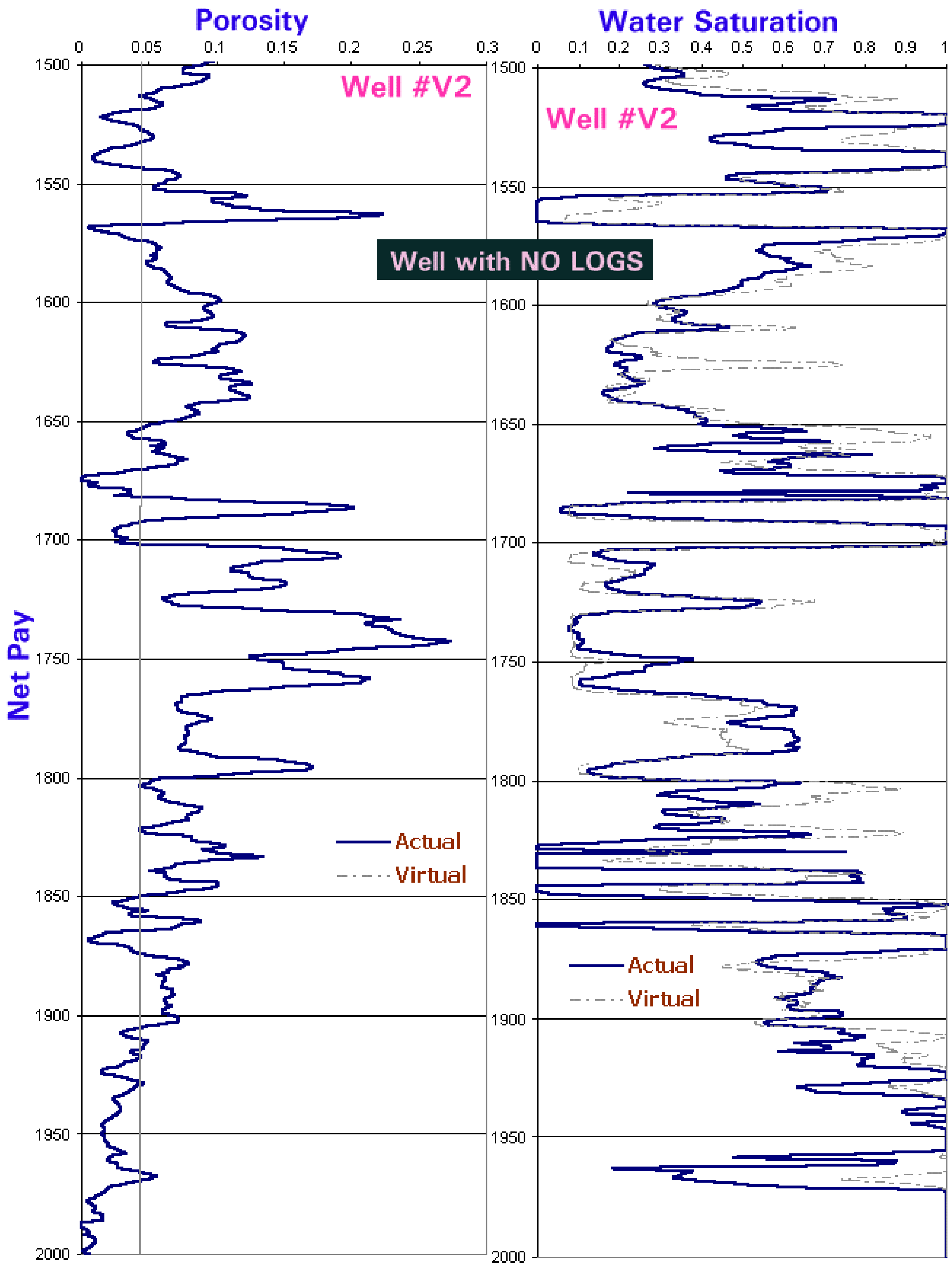

Figure 11. Porosity and saturation logs when no logs are available.