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Comparison of an Expert System to Human Experts in Well Log Analysis and Interpretation

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ABSTRACT

Comparisons of the results produced by the expert system to those produced by experts proficient in the field of log analysis are discussed using case histories from a variety of wells from many countries. The results, in general, have exceeded initial expectations for the expert system, with the system showing surprisingly "intelligent" behaviour in some circumstances and actually highlighting mistakes made by the human experts. In other examples the expert system fails to closely emulate the human expert. This failure is shown to be the result of application of knowledge gathered from outside the realm of log analysis or information that was not considered for input into the expert system. An important facet of a knowledge-based system is the development of an understanding of its own limitations, as the refusal by the system to perform an analysis in circumstances that it does not understand is critical to its overall success.

INTRODUCTION

Well log analysis and interpretation is an inexact science without precisely defined "best" methods of solving problems for any given set of circumstances. Human experts in the field apply heuristics acquired from years of learning successful techniques for particular circumstances and decisions are often based on intangibles such as patterns or shapes observed in log curves. The implementation of an expert system for log analysis and interpretation requires that the expert system emulate, to some degree, the intuitive behaviour of the human expert in searching for an acceptable solution.

References and illustrations at end of paper.

Expert systems, from the more general field of artificial intelligence, are sophisticated computer programs designed to simulate the application of human expertise to solve problems. Also known as knowledge-based systems, expert systems use facts, heuristics or rules of thumb, and employ symbolic logic and reasoning to replicate human thought processes within a specific domain [Waterman].

The problem of well log analysis was attacked using the expert system in the software product INTELLOG. Unlike most expert systems that only recommend how to perform a task, this expert system can complete the entire analysis process yielding estimates of the volume of shale, porosity, water saturation and lithology in the formation of interest.

ABOUT THE EXPERT SYSTEM

In general, expert systems consist of certain specialized components: a knowledge base, the heart of the system, contains the domain knowledge or "expertise" as denoted by an expert; an inference engine, the problem-solving knowledge, directs the process of reasoning or interpretation; a user interface provides facilities for data input and output [Shultz].

This expert system has been designed to assess all data available for a particular well through the zone of interest and give the "best" first pass interpretation. It "assumes" all available data; log curves, parameters and deposition environment has been input prior to invoking it. Although the expert system shell is capable of running in fully interactive mode, the expert system for log analysis has been designed as an assistant for inexperienced log analysts or by computer operators who have no log analysis background. For such a user, a question such as "To what degree do you believe uranium is present?" would be useless. The design of the "assistant" has therefore concentrated on enabling the expert system to determine the answers to all such questions by examining the input data.

The expert system reasons about input data, such as logs, to determine the best methods of calculating the required outputs. Central to this reasoning process is the concept of the algorithm. An *algorithm* is a set of mathematical operations impressed upon data which produce a result. For example, an algorithm called VSHgr calculates the volume of shale from the gamma ray log. The expert system's solution to the log analysis problem is a list of algorithms called a *routine*, which it then executes to produce the output data [Crain].

The design of the expert system shell makes it possible to easily add new knowledge and methods to the system. This knowledge may be extremely localized, such as a variation of the complex lithology crossplot that works well in a particular formation or area, or global, such as the reasoning process required to consider a new logging device.

OPERATION OF THE EXPERT SYSTEM

While determining the appropriate algorithms to be applied to produce the desired quantitative results, the expert system must engage in many preliminary estimations and calculations. The following is a quick overview of the thought processes of the assistant.

Determining Zone of Interest

Upon invoking the expert system, the first and only prompt to the user is that of the desired interval. The user can select the default depths as presented by the assistant or has the option to indicate depths within range of those presented. All further assessments and calculations will be carried out through this entire interval.

Normalization Of Input Data

In order to simplify the reasoning process, the expert system only thinks about logs which are expressed in basic units. For example, if a sandstone scale density porosity is given to the assistant, it will create a log scaled in density units (gm/cc or kg/cubic metre), and subsequently it will not have to be concerned about the original units of the measurement. These transformations are performed on the sonic (travel time) and the neutron porosity (limestone units), as required.

Environmental Corrections

All available environmental corrections are applied to the input data. Currently only the gamma ray and deep resistivity corrections are available to the assistant.

Detecting of Non-Porous Lithology

As many of the parameter selection techniques are based on statistical methods, the assistant examines the input data and 'flags' lithologies that would cause spurious results. Lithologies that are currently flagged are coal, anhydrite, gypsum and salt.

Estimation of Shale Volume

Many of the parameter selection techniques also depend on an initial estimate of shaliness. This estimate is obtained through the use of the standard shale calculation algorithms, but is subject to further refinement once the parameters have been defined.

Evaluation of Given Trace Elements, Formation Fluid and Lithology

The expert system assesses any data given on the presence of trace elements (uranium, pyrite and/or feldspar), formation fluids (fresh or salt water, gas and/or oil) and lithologies (sandstone, limestone and/or dolomite).

Detection of Trace Elements

If trace elements present have not been specified, the expert system attempts to detect uranium, pyrite and feldspar.

Determination of Formation Fluid

If the formation fluid has not been determined, the expert system checks, for example, crossover or deflections in the SP log to get some indication of what might be present.

Establishment of Reliable Logs

Each log present in the input is examined to determine it. reliability. The criterion for reliability are specific to each log and may include any trace elements, formation fluids and borehole conditions which would make the log unreliable.

Estimation of Lithological Make-up

If lithology has not been stated, the expert system employs algorithms implementing Hingle plots in order to determine matrix density, neutron porosity and sonic travel time. From these results the assistant determines the matrix to be one, two or three mineral models of sandstone, limestone, dolomite and/or anhydrite.

Algorithm for Computation of Volume of Shale, Porosity and Water Saturation

Having completed all of the calculations in the preceding sections, the expert system can now continue with the actual analysis of the well. The expert system considers the following methods for calculating the volume of shale:

- 1. Potassium curve
- 2. Gamma Ray log
- 3. Neutron-Density crossplot
- 4. Spontaneous Potential curve (SP)
- 5. Sonic-Density crossplot

If more than one of these methods is determined appropriate, the minimum computed values are used in further calculations.

The following methods are considered for computing porosity:

- 1. Complex lithology Neutron-Density crossplot
- 2. Shaly-sand Neutron-Density crossplot
- 3. Bulk volume water Neutron-Density crossplot
- 4. Sonic-Density crossplot
- 5. Sonic-Neutron crossplot
- 6. Density log
- 7. Neutron log
- 8. Sonic log
- 9. Electromagnetic Propagation Time log

The following methods are considered for computing water saturation:

- 1. Waxman-Smits
- 2. Simandoux
- 3. Archie
- 4. Bulk volume water
- 5. Thermal Decay Time log
- 6. Electromagnetic Propagation Time log

The following methods are considered for computing the lithological make-up:

- 1. One mineral model
- 2. Photoelectric Factor-Density crossplot
- 3. Neutron-Density crossplot (MID)
- 4. M-N plot
- 5. Density log
- 6. Sonic log

In the porosity, water saturation and lithology computations, the expert system uses the first method that is determined appropriate with the data available. These methods may be ranked in order of preference.

It should be noted that selection of any of these methods (application of the algorithm) is dependent upon availability of values for required parameters or successful execution of methods for calculating values (algorithms for parameter picking). For example, in the case of volume of shale from the gamma ray log, the values of GR0 and GR100 (the 'clean' and shale values) must be determined. If these values are not given to the assistant it attempts to define them using frequency distribution techniques.

Should all methods fail in a particular section or sections, the expert system indicates that an appropriate method cannot be determined from the given data.

TESTING THE EXPERT SYSTEM

Over one hundred wells have been tested by comparing the results produced independently by the expert system and various petrophysicists on our log analysis staff. Given the interpretive nature, complexity and subjective bias of the problem, the results have been to our satisfaction. In all of these comparison cases, the input data to the assistant was chosen to be identical to the data input for the human analysis.

We chose to present six of the more difficult and interesting cases here. These wells are difficult because of the limited amount of information given to the expert system and interesting in the way it chose to handle each situation.

Raw logs available in five of the six tests were: caliper, gamma ray, SP, neutron porosity, density porosity, sonic, shallow, medium and deep resistivity. The Morocco Test well only had available the gamma ray, sonic and resistivity logs.

In each case, the evolution of the results provided by the assistant is discussed, from the base case where only the input logs were provided, to the final results. The base case is very interesting in that it is analogous to providing a petrophysicist with a copy of a short interval of a well, and without providing him any further information, such as the name of the formation, the location of the well, or any offsetting wells, asking him for his best analysis.

Water resistivity values were provided to the assistant in five of the six cases, excluding the Offshore Test well. The methods currently provided to the assistant to calculate a water resistivity are SSP and RWa, and as both of these methods require a zone known to be water saturated, only the Offshore test well passed the assistant's selection criterion. Appendices A and B define all algorithms and parameters discussed.

CASE: Canada Test

This case is an example of an extremely successful analysis by the assistant, in that in order to produce acceptable results in agreement with the human expert, only the log data input was required.

In Figure - 1 the raw log curves for this well are presented. Figure - 2 shows how the expert system's interpretation compared with that of human expert. Table - 1 is the list of expert system interpretation parameters and computed values. Table - 2 is the list of algorithms, a routine, the expert system suggests be executed for a complete quantitative analysis. Table - 3 is the list of parameters and values input by the human expert. Table - 4 is the routine applied to the data of this well.

In the base case, that is, when only the raw data shown in Figure - 1 was presented to the assistant, the results of its analysis are in excellent agreement with those of the human expert. The additional algorithms in the expert system generated routine arise as the system computes values for interpretation parameters such as GR0 and GR100 which the human expert picked from the logs or crossplots.

The expert system and human expert used identical techniques for the calculation of shale volume, porosity and water saturation, however, on the initial pass, the assistant decided that the lithology was limestone. This was a reasonable assumption based on the results of the Hingle plots for the zone and the fact that the actual lithology is a sand-dolomite mixture below a massive anhydrite section.

The only additional information provided to the assistant for the final result was the fact that the formation was the Halfway. This knowledge, which the petrophysicist insisted on, allowed the assistant to ascertain the correct lithology, and create the excellent comparison shown in Figure - 2.

In this case an interesting observation was made. Comparison of the shale neutron porosity chosen by the expert system was significantly greater than that of the human expert. In investigating this, it became obvious that the human expert had made his pick from the wrong log. That is, he had crossed up the neutron and density porosities when making his pick. Shown are the results of the human analysis after he had corrected this error. In testing the validity of the expert system results, any major differences in comparison to the human experts are normally assumed to be caused by exceeding the limits of the assistant. However, as seen here, this is not always true.

(see Figure - 1&2, Table - 1 through 4, APPENDIX A&B)

CASE: China Test

This case is an example of a well in which the expert system had a very difficult time in achieving acceptable results, until additional pertinent data was input by the operator.

When the raw data was input for this well, the deep resistivity log was incorrectly entered off depth. This caused the expert system to have difficulty establishing resistivity parameters until the depth shift was corrected. Currently, the assistant is unable to identify this type of problem.

Initially, in the base case, the expert system immediately refused to analyze this well. The cause of this refusal was the fact that the gamma ray log was not scaled in API units. After estimating values for GR0 and GR100 to be 6 and 8 respectively, the assistant decided that these were impossible values and failed the gamma ray log as a shale indicator. Upon investigation of all other methods of obtaining the volume of shale, for various reasons all failed and so the assistant refused to continue analysis of this well.

The expert system was then given parameter values for the gamma ray log in the clean and shaly zones. Again the assista· refused to complete the analysis of the well. In this case, th refusal was due to the lack of porosity variation in the pay zone, causing the Hingle plot to fail to give a reasonable value for matrix travel time. The value was that used by the human expert established from core to log correlations from adjacent wells. The assistant was then given a value for the matrix travel time that it had chosen from a previous analysis and the fact that the lithology was sand. With this information in place, the results shown in Figure - 3 were produced.

Considering the difficulties involved in analyzing this well, the fact that the assistant can produce a good analysis given only four additional facts is extremely encouraging. Once these facts were provided, the methods chosen by the petrophysicist and the expert system were essentially identical.

(see Figure - 3)

CASE: Columbia Test

In this well, the expert system and the human expert show a substantial difference of opinion.

There was bad hole through the entire interval, excluding the zone of interest. The human expert computed the porosity using a complex lithology crossplot and chose neutron and density shale parameters to compensate for the bad hole. The expert system failed the neutron and density logs in reliability, electing to u the sonic log, as it felt the sonic log was the least affected by ba hole. It is not allowed (and we are not about to teach it how) to pick arbitrary values to compensate for the use of methods that it feels are inappropriate. The assistant was given the matrix travel time for the same reason and in the same manner as in the previous example.

Except for the difference of opinion regarding the handling of the borehole conditions, the expert system and the human expert used much the same methods for the rest of the analysis, but due to the differences in the methods of calculating porosity, there was a slight variation in the quantitative results presented in Figure - 4. Both established the zone to be a sandstone.

(see Figure - 4)

CASE: Louisiana Test

This is another successful example where only the raw input logs were required by the expert system to complete its analysis.

Again, in this well, we see major differences of opinion between the expert system and the petrophysicist. The volume of shale, porosity and water saturation methods chosen were all different. The human expert used the neutron-density crossplot to compute the volume of shale, citing the lack of definition in the gamma ray and SP logs. The assistant, on the other hand, felt that a sir nificant amount of crossover was present on the neutron and der sity logs, possibly indicating gas, and so chose the gamma ray log.

The human expert used the shaly sand neutron-density crossplot to determine porosity. The expert system, however, in a shaly-sand, prefers to compute the porosity using the bulk volume water method if a clean section exists. In water saturation computations the assistant was then biased to use the bulk volume water method again, whereas, the human expert chose the Simandoux method.

In spite of the fact that different methods were used in each computation, comparable results were produced. The zone was established as sand in both analyses.

(see Figure - 5)

CASE: Morocco Test

In this well the expert system again refused to analyze the base scenario. The reason for this failure was the poor selection of input data for the assistant to reason about. In order to determine the clean, shale, and matrix parameters, the assistant needs a statistically viable number of data points for both matrix and shale to be contained in the input data. The humans' luxury of flipping back a few pages on the log to see what the shale looks like is not an option for a computer. If you want the assistant to reason about some data, you have to input it.

The expert system and the human expert selected the gamma ray log to compute the volume of shale. The assistant attempted to establish clean and shaly values from the gamma ray log using a histogram, but due to the lack of good representation of a shaly zone was unable to do so.

The parameter values for shale and matrix were therefore given to the expert system. Using this information, the assistant was able to complete the analysis using the same methods as the human expert. They both selected sonic porosity log and both chose to compute the water saturation using the Simandoux method. Had the expert system been given a value for the resistivity of shale through the zone (which is reasonable due to the argument above), the water saturation results would have been even closer to that of the human analysis. Again a lithology of sandstone was established.

(see Figure - 6)

CASE: Offshore Test

Again, in this example, the expert system was not given any parameters. As there was a water bearing zone below the hydrocarbon interval, the assistant was able to calculate a water resistivity value to use in determining water saturation.

A slight difference of opinion occurred as the expert system chose to use both the gamma ray log and the neutron-density crossplot to compute the volume of shale while the human expert used only the gamma ray log. This difference is due to the fact that the expert system looks at all available information in making its analysis, whereas human experts may look at the gamma ray log first, electing to use it without further consideration. The expert system and the human expert computed the porosity using the neutron-density crossplot for complex lithology method. Because of the slight variations in the volume of shale computed, it results in a variance in the porosity computed. The same method, Simandoux, was applied by the expert system and the human expert to compute the water saturation, but the previous differences in shale volume, porosity and the selection of a value for RW result in the slight differences presented. A two mineral model, sandstone and limestone, was proposed by both the expert system and the human expert.

(see Figure - 7)

EVALUATION OF PERFORMANCE

When an expert in well log analysis makes an interpretation, that person may be familiar with the formation, or the area. He can use data from core to log correlations with adjacent wells and can make some preliminary assumptions or estimations regarding trace elements, formation fluid and lithology. The expert system does not have these advantages. It only knows what users input. In evaluating the results of the expert system in comparison to human experts the following important points were discovered:

- In the case of bad hole everywhere but through the pay zone, the expert system cannot choose arbitrary parameters to compensate for the fact it cannot determine shale values. It must choose the method that it feels is least affected by the bad hole.

- Human experts make correlations to the well in question given data from adjacent wells or by flipping back a few pages in the log. The expert system, however, does not the knowledge or means of "looking" at adjacent wells and cannot 'flip' back through the log if the data was not input.

- The presence of trace elements, formation fluid and lithology can be determined by the system, however. If the system fails to correctly identify these, the formation name can be given to the assistant so it can search its database to find values associated with that formation. To a large extent this emulates the experience of the human expert.

- If a curve has been incorrectly entered, the expert system currently has no way of detecting this. It must be corrected by the user. This is a limitation of the current methods for identifying reliable logs.

- The expert system needs API standard well log curves.

CONCLUSIONS

This paper presents some comparisons of the expert system developed within INTELLOG to human experts within the field of well log analysis.

Results of these tests proved to be most encouraging, exceeding our initial expectations. If the expert system had only performed at the level of the base cases, we would have felt that it was a useful tool, however, with the addition of knowledge of formations and areas, performance is heightened.

Most important however has been the understanding of the scope and limitations of the expert system regards to adequate selection of input data. Our practice of giving the expert system precisely the data that the human selected for analysis was the cause of most of its difficulties in this study. Allowing for human input where difficulty is experienced or essential data is lacking makes the system a powerful tool.

The development of the expert system presented has not been intended to replace the traditional techniques used by well log analysts in interpretation, but rather, to offer assistance in making a reasonable and viable first pass interpretation. This allows the expert system to be used and less experienced individuals to function near the level of proficient petrophysicists.

Having demonstrated the success of an expert system in a log analysis package, we see industry acceptance of its application in routine log analysis. An ideal application of the expert system is the storage of a company's proprietary knowledge and making it available to less experienced personnel.

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APPENDIX A - PARAMETERS and DEFINITIONS (SI)

A ....tortuosity exponent
ANHY# ....anhydrite identification trigger
ANHYDN ....anhydrite density log trigger
ANHYDT ....anhydrite sonic log trigger
ANHYGR ....anhydrite gamma ray log trigger
ANHYNT ....anhydrite neutron log trigger
ANHYRT ....anhydrite resistivity log trigger
DELTF ....fluid sonic travel time
DELTMA ....matrix travel time
DELTMA1 ....matrix travel time for mineral 1
DELTMA2 ....matrix travel time for mineral 2
DELTMA3 ....matrix travel time for mineral 3
DELTSH ....sonic travel time for shale
DELTW ....sonic travel time for water
GR0 ....gamma ray log value for sand
GR100 ....gamma ray log value for shale
M ....cementation exponent
MLITH1 ....M lithology value for matrix 1
MLITH2 ....M lithology value for matrix 2
MLITH3 ....M lithology value for matrix 3
N ....saturation exponent
NLITH1 ....N lithology value for matrix 1
NLITH2 ....N lithology value for matrix 2
NLITH3 ....N lithology value for matrix 3
PHIDSH ....density porosity log shale line
PHIMAX ....maximum porosity for clean zone
PHINSH ....neutron porosity log shale line
RHOF ....formation fluid density
RHOMA ....matrix density
RHOMA1 ....matrix density for mineral 1
RHOMA2 ....matrix density for mineral 2
RHOMA3 ....matrix density for mineral 3
RHOSH ....density of shale
RHOW...........water density
RSH ....shale resistivity
RW ....water resistivity
RWT.............water resistivity at formation temperature

APPENDIX B - ALGORITHMS and DEFINITIONS (SI)

3MM_sand_lime_dolo
..................3 mineral sandstone-limestone-dolomite
BCORgr ....borehole correction for gamma ray
DELTSH_VshDeltxplot
..................determines sonic travel time in shale
DELTc ....shale corrected travel time
DELTma ....apparent matrix travel time
DENS ....creates density log
DENSc ....shale corrected density log
FIND ANHYDRITE
..................detects anhydrite
MNlith ....calculates M and N logs
PHIDSH_VshPhidxplot
..................determines shale density porosity

PHIDc ....shale corrected density porosity log
'HINSH_VshPhinxplot
..................determines shale neutron porosity
PHINc ....shale corrected neutron porosity log
PHINl ....neutron porosity log limestone units
PHISc ....shale corrected sonic porosity log
PHIbal ....computed porosity balancing
PHIxcl ....porosity from complex lithology crossplot
RESDc2 ....invasion correction for deep resistivity log
RHOma ....apparent matrix density
RSH_VshRtxplot ..determines shale resistivity
RW@FT ....water resistivity at formation temperature
SWs ....water saturation Simandoux
SWsmth ....water saturation smoothing
VROCK3mn ......3 mineral model M and N
VSHbal ....computed shale volume balancing
VSHgr ....volume of shale from gamma ray
VSHmin ....minimum computed shale volume
draw_GR_baseline .shale volume estimation from gamma ray
draw_SP_baseline .shale volume estimation from SP
get_range ....prompts user for desired interval
histo_GR0 ....clean gamma ray log value from histogram
histo_GR100 ......shaly gamma ray log value from histogram
stand_ANHY# ....anhydrite identification trigger default
stand_ANHYDN ..anhydrite density log trigger default
stand_ANHYDT ..anhydrite sonic log trigger default
stand_ANHYGR ..anhydrite gamma ray trigger default
stand_ANHYNT ..anhydrite neutron log trigger default
stand_ANHYRT ..anhydrite resistivity log trigger default
stand_Ald ....carbonate tortuosity exponent default
stand_DELTF .....formation fluid sonic travel time default
stand_DELTMAd .dolomite matrix travel time default
stand_DELTMAl ..limestone matrix travel time default
stand_DELTMAs ..sandstone matrix travel time default
stand_DELTWs ...salt water sonic travel time default
stand_MLITHd ....M for dolomite default
stand_MLITHl ....M for limestone default
stand_MLITHs ....M for dolomite default
stand_Mld ....carbonate cementation exponent default
stand_NLITHd ....N for dolomite default
stand_NLITHl ....N for limestone default
stand_NLITHs ....N for sandstone default
stand_Nld ....carbonate saturation exponent default
stand_PHIMAXld .carbonate maximum porosity default
stand_RHOMAd ..dolomite matrix density default
stand_RHOMAl ...limestone matrix density default
stand_RHOMAs ..sandstone matrix density default
stand_RHOWs ....salt water density default

Table - 1

EXPERT SYSTEM PARAMETERS and VALUES

RW	0.05	A	1
RWT	25	M	2
ANHY#	3	N	2
ANHYDN	2970	RSH	19.8432
ANHYDT	164	RHOMA1	2650
ANHYGR	20	RHOMA2	2710
ANHYNT	0.01	RHOMA3	2830
ANHYRT	200	RHOF	1000
GR0	28.1469	DELTMA1	182
GR100	115.58	DELTMA2	170
DELTF	616	DELTMA3	144
DELTMA	165.333	MLITH1	0.81
DELTSH	182.732	MLITH2	0.827
RHOSH	2679.84	MLITH3	0.778
RHOMA	2730	NLITH1	0.628
RHOW	1000	NLITH2	0.585
PHINSH	0.120418	NLITH3	0.524
PHIMAX	0.3	DELTW	616

Table - 2

EXPERT SYSTEM ROUTINE

get_range	stand_RHOWs
BCORgr	PHIDc
RESDc2	PHINl
stand_ANHY#	PHINSH_VshPhinxplot
stand_ANHYDN	PHINc
stand_ANHYDT	PHISc
stand_ANHYGR	PHIxcl
stand_ANHYNT	stand_PHIMAXld
stand_ANHYRT	PHIbal
FIND ANHYDRITE	RW@FT
draw_SP_baseline	stand_Ald
draw_GR_baseline	stand_Mld
VSHmin	stand_Nld
histo_GR0	RSH_VshRtxplot
histo_GR100	SWs
VSHgr	SWsmth
stand_DELTF	3MM_sand_lime_dolo
stand_DELTMAs	stand_DELTWs
stand_DELTMAl	MNlith
stand_DELTMAd	RHOma
DELTSH_VshDeltxplot	DELTma
PHIDSH_VshPhidxplot	stand_MLITHs
VSHbal	stand_MLITHl
DELTc	stand_MLITHd
stand_RHOMAs	stand_NLITHs
stand_RHOMAl	stand_NLITHl
stand_RHOMAd	stand_NLITHd
DENSc	

Table - 3

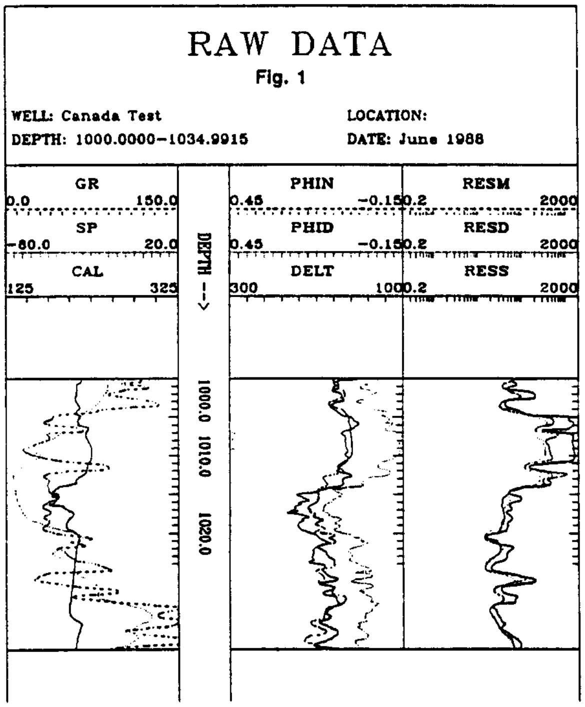
HUMAN PARAMETERS and VALUES

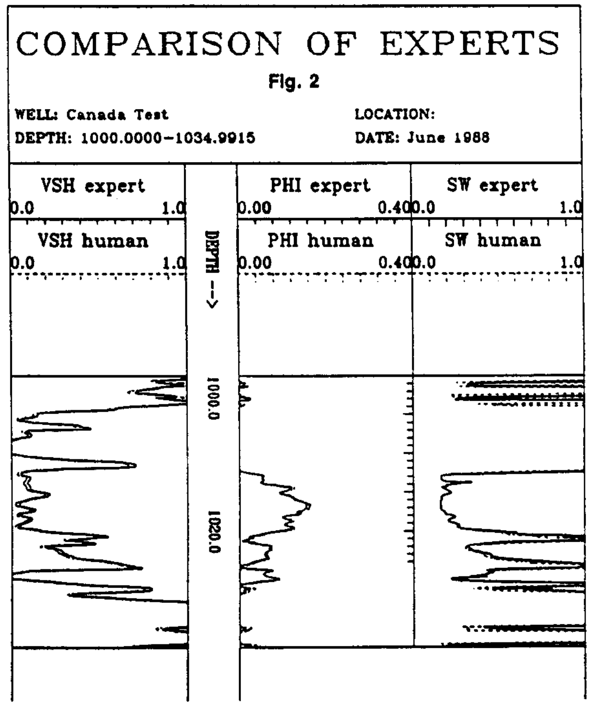
A	1	MLITH2	0.8
ANHY#	3	MLITH3	0.72
ANHYDN	2970	N	2
ANHYDT	164	NLITH1	0.628
ANHYGR	20	NLITH2	0.524
ANHYNT	0.01	NLITH3	0.525
ANHYRT	200	PHIMAX	0.35
DELTF	616	PHINSH	0.2
DELTMA	168	RHOMA	2710
DELTMA1	168	RHOMA1	2650
DELTMA2	143	RHOMA2	2870
DELTMA3	164	RHOMA3	2980
DELTSH	182	RHOSH	2700
DELTW	610	RHOW	1100
GR0	30	RSH	15
GR100	120	RW	0.05
M	2	RWT	25
MLITH1	0.865		

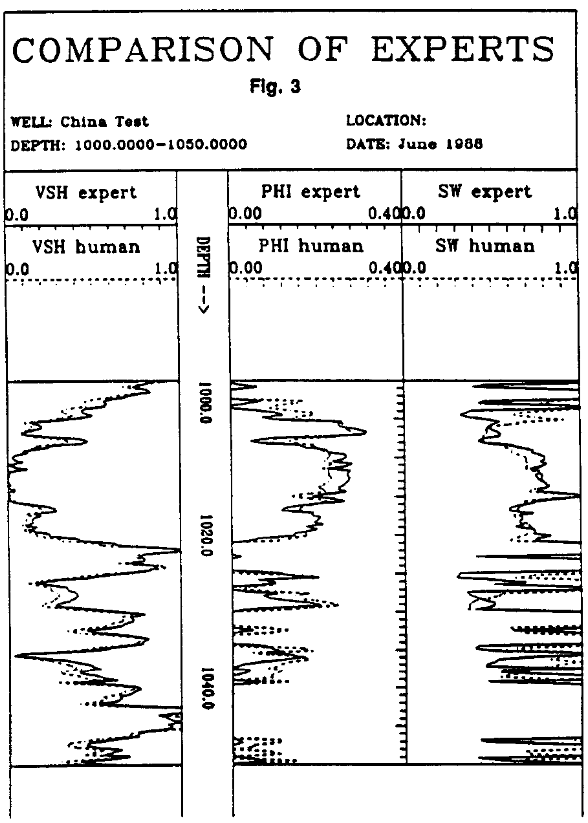
Table - 4

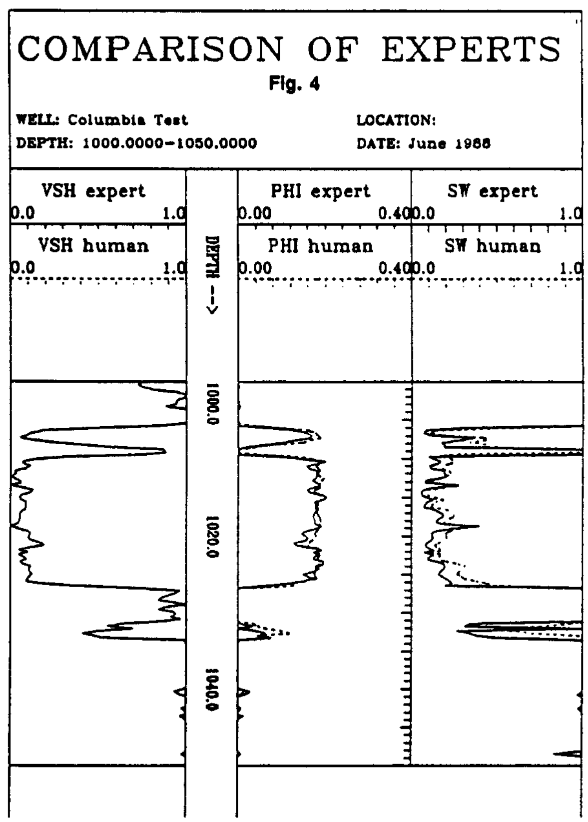
HUMAN ROUTINE

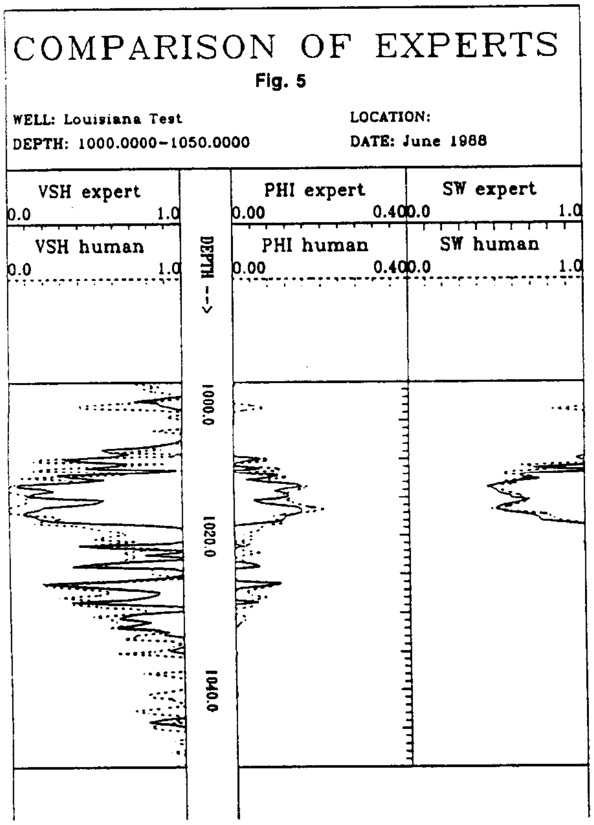
VSHgr	DELTc
VSHbai	MNlith
DENS	VROCK3mn
DENSc	RHOma
PHINl	RW@FT
PHINc	SWs
PHIxcl	SWsmth
PHIbal	

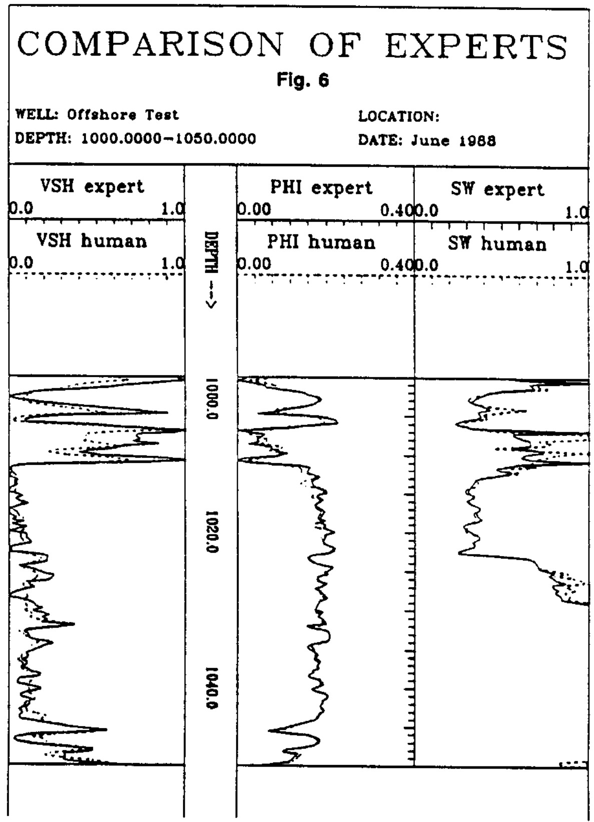

RAW DATA
Fig. 1
WELL: Canada Test
LOCATION:
DEPTH: 1000.0000-1034.9915
DATE: June 1988
GR
0.0 150.0
SP
-80.0 20.0
CAL
125 325
DEPTH -->
PHIN
0.45 -0.15
PHID
0.45 -0.15
DELT
300 100
RESM
0.2 2000
RESD
0.2 2000
RESS
0.2 2000
1000.0
1010.0
1020.0

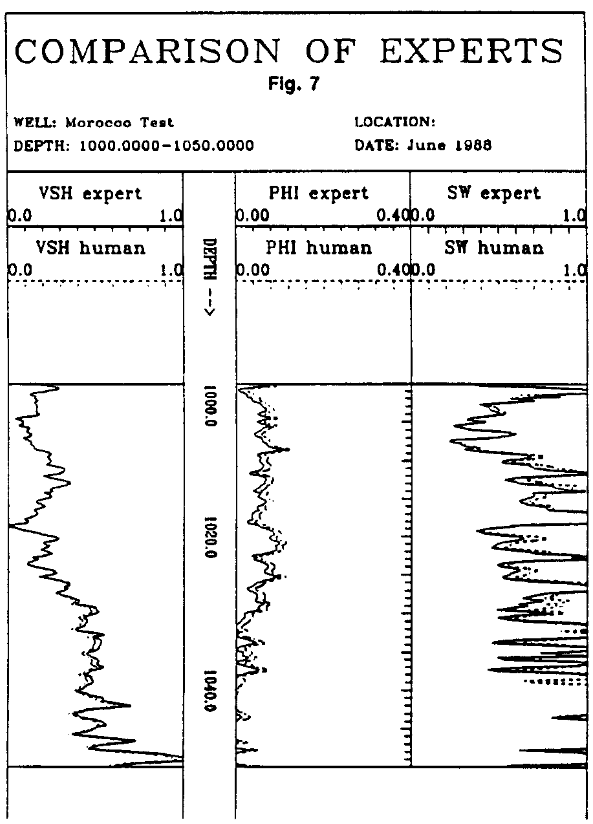

COMPARISON OF EXPERTS
Fig. 2
WELL: Canada Test
LOCATION:
DEPTH: 1000.0000-1034.9915
DATE: June 1988
VSH expert
0.0 1.0
VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0


COMPARISON OF EXPERTS
Fig. 3
WELL: China Test
LOCATION:
DEPTH: 1000.0000-1050.0000
DATE: June 1988
VSH expert
0.0 1.0
VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0
1040.0


COMPARISON OF EXPERTS
Fig. 4
WELL: Columbia Test
LOCATION:
DEPTH: 1000.0000-1050.0000
DATE: June 1988
VSH expert
0.0 1.0
VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0
1040.0


COMPARISON OF EXPERTS
Fig. 5
WELL: Louisiana Test
LOCATION:
DEPTH: 1000.0000-1050.0000
DATE: June 1988
VSH expert
0.0 1.0
VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0
1040.0


COMPARISON OF EXPERTS
Fig. 6
WELL: Offshore Test
LOCATION:
DEPTH: 1000.0000-1050.0000
DATE: June 1988
VSH expert
0.0 1.0
VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0
1040.0


COMPARISON OF EXPERTS
Fig. 7
WELL: Morocco Test
LOCATION:
DEPTH: 1000.0000-1050.0000
DATE: June 1988
VSH expert
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VSH human
0.0 1.0
DEPTH -->
PHI expert
0.00 0.400
PHI human
0.00 0.400
SW expert
0.0 1.0
SW human
0.0 1.0
1000.0
1020.0
1040.0