LOG/MATE ASSISTANT

THE INTEGRATION OF AN EXPERT SYSTEM IN A LOG ANALYSIS DOMAIN

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ABSTRACT

This paper details the interactive use of an expert system for log analysis. The system LOG/MATE ASSISTANT is based on a fourth generation log analysis package LOG/MATE ESP.

Each of the six functions of LOG/MATE ASSISTANT:

1. database
2. algorithm processor
3. interactive graphics
4. report generator
5. data communications
6. inference engine (expert system)

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are described in general. The results of the use of each function are also detailed.

The LOG/MATE ASSISTANT expert system is completely interactive and totally data driven. The user has complete control from the input screens to the reports that are generated. Additionally the user can describe the log analysis problem in terms of functions, frames, rules, pre-conditions, post conditions and inheritance.

We have implemented a frame based organization of functions to reason about the log analysis problem. We distinguish between abstract functions, reasoned about by name, and algorithms, or syntatic representations for computing a function. While we reason about abstract functions, we execute algorithms to produce values to assist in the reasoning process for log analysis.

The overall system is designed to assist anyone from a novice to petrophysics expert by providing the expertise of a seasoned petrophysicist in the domain of log analysis.

INTRODUCTION

The goal of the LOG/MATE ASSISTANT project was to develop a knowledge-based system capability for the existing LOG/MATE ESP log analysis package. Such programs are often called expert systems. Most systems of this nature do not achieve the capabilities of a true domain expert, so the term knowledge-based system is more appropriate and more descriptive. We have achieved a practical knowledge based system for the building of expert domains. The first domain to be implemented is the log analysis from LOG/MATE ESP using the knowledge of a petrophysics expert to resolve the many inticacies of well log analysis.

This involved creating and integrating an inference engine to control the functionality of the LOG/MATE ESP program, and to act as an assistant or advisor to the user. It is an intelligent, knowledge-based, interface between the user and the existing complex program. The following six functions comprise the expert system building tool (ESBT) that was developed during the project:

1. database and file manager
2. compute (algorithm processor)
3. interactive colour graphics
4. report generator
5. data communications
6. inference engine (expert system)

This paper has two parts. The first describes the expert system building tool (ESBT). The second the expert system LOG/MATE ASSISTANT.

The expert solution to the log analysis problem is superimposed on the data base. As the system is completely generic it has no knowledge of the log analysis domain. All of the structure of the log analysis domain is contained in the database and can be interactively modified or revised. This means that a user can easily modify the system to accomodate a new tool or technique by simply changing part of the information contained in the database. Currently LOG/MATE ASSISTANT has approximately 400 frames and 500 algorithms.

The ESBT System Organization and the Expert System are described in the body of this paper.

SYSTEM ORGANIZATION

The functional organization of the system is shown in FIGURE 1 and is made up of the functions indicated above. Each of the six functions is described briefly in the following paragraphs:

DATABASE

The database is an entity set relational database that allows the user to interactively define his data base. This may be as series of relations or as a linked list or any combination thereof. It is in general similar to all other databases in that it contains a series of records. The names of records of a common type are listed in a catalogue.

Various records are attached or related to each other. The attachements allow very rapid searches to be made by the program for required data, K and reduce processing time greatly. The database and the attachments along with the relations are defined when the knowledge system is designed. Records can also be attached or detached by the user at a later time by use of the data file manager.

Catalogues and records can be tiered. Access to lower level catalogues and records is obtained by working through the levels until the desired layer is reached. It is the attachments that create the structure to the database. The structure can be unique for a well, or pervade the whole system. The structure can be changed at any time by the user.

Depending upon the amount of disk space available any number of data bases may be available to the user. Information may be shared between between databases.

Structured query language (SQL) is partially implemented at this time. A future release of the program will contain an ANSI standard set of SQL.

INTERACTIVE COLOUR GRAPHICS

The interactive colour graphics are controlled by the database and as such allow the user to define any type of two dimensional chart. In the case of LOG/MATE ASSISTANT the database has been set to give many types of depth plot or crossplot (with as many tracks as may be desired or required). The graphics area may contain a combination of any desired plot types.

The size of the graphic area is larger than the the screen on the computer. This allows the user to prepare graphs and charts larger than the size of the CRT. The chart or graph may be viewed by scrolling the desired area or by zooming so that the whole chart is visible in the CRT screen area.

The ESBT allows the user to use on screen editing of data. The cursor or mouse may be used to shift, rescale, redraw, or delete data and traces. As the graphics section has been implemented using the graphical kernel system (GKS) the resulting chart may be directed to any class of output device. Examples are shown in Figures 2a and 2b.

MATHEMATICAL PROCESSING

The basic element of mathematical processing is the algorithm. This is handled by the algorithm processor. Algorithms are lexically analysed, parsed, compiled and placed in the database for use when the program or inference engine require data or a computation. The algorithm processor is an optimizing vector processing token threaded language.

A series of algorithms are selected either by the user or by the expert system to form a routine. These algorithms are then processed in a sequential fashion. An algorithm might be compared to a subroutine or a function in standard programming. A series of routines form a module that will analyse a problem. In the case of log analysis the routines form a solution to the analysis of a well based on the information available or calculated from information contained in the database.

A computation consists of a table of zone depths, the appropriate routine for each zone, and its associated parameter or constants file. It acts like a miniature runstream to control the calculations of many zones in sequence. Algorithms for the expert system LOG/MATE ASSISTANT are contained in the standard database.

Single algorithms or complete routines may be run interactively under user control, or under runstream control by the data manager. An example of an algorithm is shown in Figure 3, and a sample of a routine is shown in Figure 4.

REPORT GENERATOR

Tabular and text reports can be generated from data in the database through user defined formats. Standard reports for log analysis are contained in the database. A standard log analysis report, for example, can gather the correct pool, project, well name, and hydrocarbon volume summary and place them in correct context within the body of a report.

Reports can be generated from raw data, calculated data, or text.

The report formats are held in records contained in the database, along with all the other data and plot formats.

The report generator language lets the user specify page format - placement of headers, footers, titles, and text on the page. Numerous processing commands can be embedded in reports to perform mathematical functions or to extract data elements from the database. In the case of LOG/MATE ASSISTANT standard reports are delivered with the database.

DATA COMUNICATIONS

The data communication function relates to moving data into and out of the system, and offers extensive copy, backup, archive and restore facilities.

The system supports a LAN environment for multi user environment using IEEE-488 (HP-IB), IEEE-403 (ETHERNET), or RS-232 under UNIX.

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Data communications to remote computers is available via RS-232 and IEEE-403. Currently an inverse report generator is in the process of development to describe and transfer data in foreign computer files to the ESBT data base. At present the system supports methods of translating Schlumberger LIS and Dresser BIT tapes. The report generator can also be used to prepare ASCII files for standard type transmission to other remote computers.

INFERENCE ENGINE

The inference engine is a frame based organization of functions that reasons about behaviour and generates algorithms for new functions. The engine distinguishes between abstract functions, reasoned about by name, and algorithms, or syntatic representations of methodologies for computing a function. While the engine reasons about abstract functions, it must execute some algorithms in order to produce values to assist in the reasoning process.

A frame is the basis of the inferencing technique and is contained in the database. A sample frame is shown in FIGURE 5. This indicates that a frame is made up of:

1. a name (function) to be reasoned about.
2. parameters that are required by the function
3. results of the reasoning process
4. pre-conditions required before the function can be reasoned about or calculated.
5. post conditions that are to be resolved to a primitive if the result of the reasoning process is determined to be true.
6. the type of logic to be used in evaluating the body of the function. This may be an and, or, any, all or primitive as applied to the functions described in the body of the frame.
7. the body of the frame that contains one or more names of other frames or names of functions that are to be evaluated.

The inference engine recursively calls the frames and processes each part of the frame. Each frame may have sub frames that recursively traverse other frames. This is a network traversal algorithm and is specific to the knowledge representation and domain of functions. Other systems talk of forward or backward chaining. This system traverses the knowledge base in any direction depending upon the information available and the status of the functions reasoned about.

FIGURE 6 shows an example of the network of functions and their relationships to each other and to the domain. This indicates that to solve the log analysis problem the inference engine must resolve the functions of volume of shale, porosity, saturation and rock lithology. To do this it must first resolve whether to compute VSH from the sp or from the gamma ray log. To do this it must first resolve whether the sp log exists or does not exist. To determine this it simply looks at the data base and resolves the problem. It can therefore retrace its logic and resolve the compound functions until all are resolved to primitives. Backtracking through the successful resolutions builds up the determined algorithm.

Knowledge captured in frames is inherited implicitly when a precondition is executed. The inheritance features of class structures (explicit inheritance) is not implemented at this time.

An explanation facility is part of the inference engine. This facility provides the user with a process to ask the expert why a particular routine was selected. This is to allow the user to challenge or understand the reasoning process. By questioning the reasoning process a novice may better understand or gain insight into the domain. The expert system then becomes a teacher to the novice or allows another expert to revise or add into the expert system his expertise.

THE EXPERT SYSTEM

While running LOG/MATE ASSISTANT the user has the option to perform log analysis with the suggestions made by the expert system. The expert system indicates algorithms to be executed by LOG/MATE ASSISTANT corresponding to four computations: volume of shale, porosity, water saturation, and lithology. The feasibility of an algorithm for any calculation is determined by the evaluation of associated parameters, preconditions, type, postconditions, and results. From this the expert system recommends a list of algorithms for computation and a list of parameter assigning methods to be executed by LOG/MATE ASSISTANT to complete the analysis.

WELL INFORMATION

The expert system takes into account the following information that may be present in the database or determined by log response evaluation regarding a particular well:

Logs present:	gamma ray
	spectral gamma ray curve
	   uranium curve
	   thorium curve
	   potassium curve
	SP
	resistivity
	density
	density porosity
	neutron
	neutron porosity
	sonic
	sonic porosity
	TDT
	dielectric
	PED
	core porosity

Hole condition:	based on types of logs used correction curves from logs caliper and bit sizes
Lithology:	shale sandstone limestone dolomite
Trace elements:	uranium pyrite feldspar
Formation fluids:	fresh water salt water gas oil

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RULE CONTENT

The rules of the expert system can be divided into two groups: property assessment and algorithm assessment.

In the first phase, property assessment, the expert system attempts an initial determination of lithology, trace elements, and formation fluids present.

In this initial attempt lithology is determined by the response evaluation of the gamma ray log and the results of a Hingle plot. Trace elements are detected by examining the gamma ray and uranium, thorium and potassium curves. Formation fluid is determined through the detection of crossover or approaching crossover of the density-neutron porosity combination along with fluctuations in the resistivity and gamma ray log, and deflections in the SP log. Once a property is determined the result is asserted, and that result will be used as a precondition in algorithm assessment.

In assessing algorithms for computation, the expert system first checks the availability of parameter assigning methods for all parameters associated with an algorithm. Preconditions are composed of logs present, hole condition requirements, lithologies, trace elements, and formation fluids allowed, the evaluation of particular log responses, correctional algorithms, and required results from previously assessed algorithms. Frame type is then considered, which is a control mechanism for frame accessibility. Finally, postconditional algorithms, primarily correctional algorithms, must be successfully executed. Should parameter methods be available and all preconditions and postconditions completed, that algorithm within the body is determined to be feasible. Hence, results are asserted and assessment continues.

The expert system considers all volume of shale algorithms for computation (corresponding to type "AND"). This consideration is in contrast to porosity, water saturation, and lithology computation algorithms, where the first feasible method is selected (type "OR"), without any further assessments (these methods are detailed in the APPENDIX).

The final suggestions as recommended by the expert are a collection of volume of shale, porosity, water saturation, and lithology computational algorithms, along with the associated parameter assigning methods, and any further postconditional algorithms associated with the algorithms selected.

RULE REPRESENTATION

The expert system is frame based. At present LOG/MATE ASSISTANT consists of approximately 400 frames. The frames are composed of the following attributes:

name
parameters
results
preconditions
postconditions
type
body

The appendix shows in tabular form all rules for assessing lithology and computational algorithms (in familiar form for the reader). It also includes the LOG/MATE ASSISTANT mnemonics for algorithms, associated parameters, and parameter assigning methods. For example, a method for calculating the volume of shale is represented in three frames with attributes values of:

name	VSHgr
parameters	GR0 GR100
results	VSHfnd
preconditions	el_GR_pr te_urn_not BCORGR
postconditions	VSHmin VSHbal
type	OR
body	VSHgr1 VSHgr2

name	VSHgr1
parameters	none
results	none
preconditions	te_fld
postconditions	VSHcl
type	PRIMITIVE
body	VSHgr

name	VSHgr2
parameters	none
results	none
preconditions	none
postconditions	none
type	PRIMITIVE
body	VSHgr

The meaning of the preceding frames are expressed more simply as:

> "the feasibility of the algorithm for determining the volume of shale using the gamma ray method is assessed in the following manner:
>
> if the appropriate parameter assigning methods are available for the parameters GRO and GR100, the gamma ray log is present in the data base and reliable according to hole condition requirements (el_GR_pr), and the trace element uranium is not present from evaluating log responses (te_urn_not), and borehole correction (BCORGR) is successfully evaluated there are two options available (as indicated in the body of the frame) VSHgr1 or VSHgr2. If the trace element feldspar is also present (te_fld) the first option will be selected, otherwise it will be the alternative. Postconditions of the chosen option are then evaluated (in the example this would pertain only to the first option which is a
> K non-linear correction (VSHcl). If successful, the postconditions and volume of shale minimum (VSHmin) and balance (VSHbal) are evaluated and must also prove successful. The result (VSHfnd) is asserted and the calculated volume of shale may be used in any future calculations. Hence, the assessment of this algorithm is complete."

ZONATION

A zone is defined by a gross change in bulk volume, lithology and/or formation fluid. Zonation is used to distinguish stratigraphically unique units of rock in a formation.

Since a zone of interest in a particular well is usually known by the log analyst or is documented in a geological report, zonation is at the discretion of the user. Property and algorithm assessments will then be performed incrementally (as chosen by the user) within that zone.

LOG/MATE ASSISTANT does contain two algorithms for zonation: a classification algorithm, and a cluster analysis. The first involves classifying each response on the available logs as high or low. Lithology is then determined from eight combinations of shale, sandstone, limestone, dolomite, and anhydrite. The second approach is stratigraphically constrained. Intervals of similar characteristics are identified from a variety of logs. The user then states the number of zones desired.

CERTAINTY FACTORS

Every precondition to the use of an algorithm has a certainty factor attached. These factors then determine the most to the least appropriate method to use in any calculation. Note that a particular precondition, depending on the context in which it is used, can have a varying effect, hence a variance in weighting.

ITERATION

An iterative routine achieves a result by performing a series of operations until some specified condition is met. If an inconsistency is detected in the final results of LOG/MATE ASSISTANT it is usually due to an incorrect initial assessment of lithology by the expert system. According to the lithological assessment of the Hingle plot, LOG/MATE ASSISTANT chooses a model and solves the equation of that model. At the conclusion of the investigation the results can evaluated as correct or incorrect. If incorrect then a new model can be ascertained and evaluated. This process of modification and re-evaluation is repeated at every increment within the zone of interest until reasonable and/or desired results are obtained. K

CONCLUSION

A computer system has been developed for building expert systems. The first system to be implemented is in the domain of log analysis and the expert system is known as LOG/MATE ASSISTANT. This expert system is currently made up of 400 frames and 500 algorithms.

Frames and algorithms may be entered into the database on line at the discretion of a knowledgeable user. This allows the user to add knowledge, or to install the algorithms for new logging devices as they become available. Area specific information may also be inserted into the data base for inferencing purposes.

BIBLIOGRAPHY

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A Model for Generating Natural Functions. In Coupling Symbolic and Numeric Computing in Knowledge Based Systems. Seattle.

2. Crain, E. Ross, The Log Analysis Handbook. Pennwell Books
Volume 1: Quantitative Log Analysis Methods

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Structure of Log/Mate Assistant

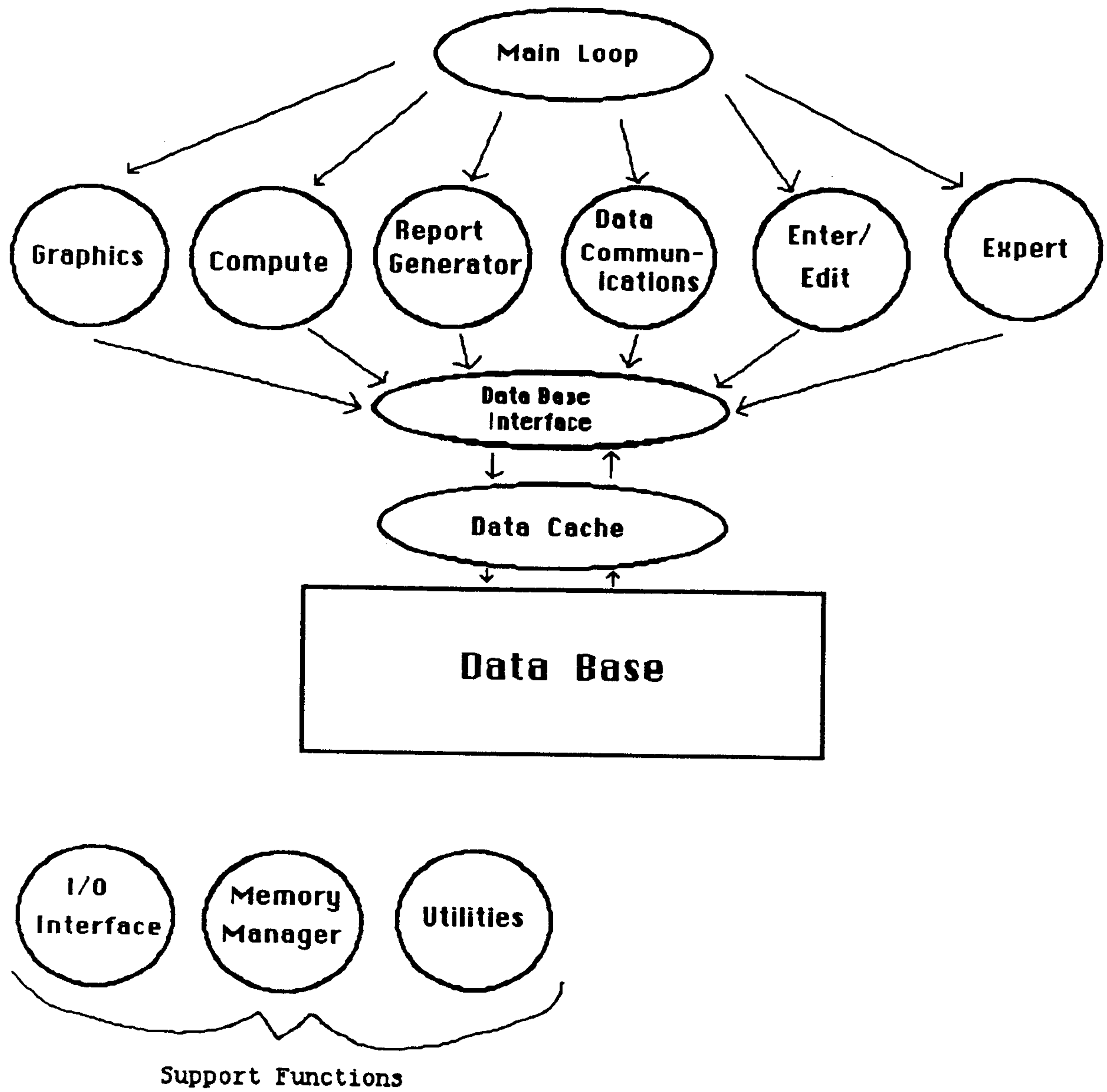

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Figure 1.

The structure of Log/Mate Assistant consists of six main modules, a data base, and support functions.

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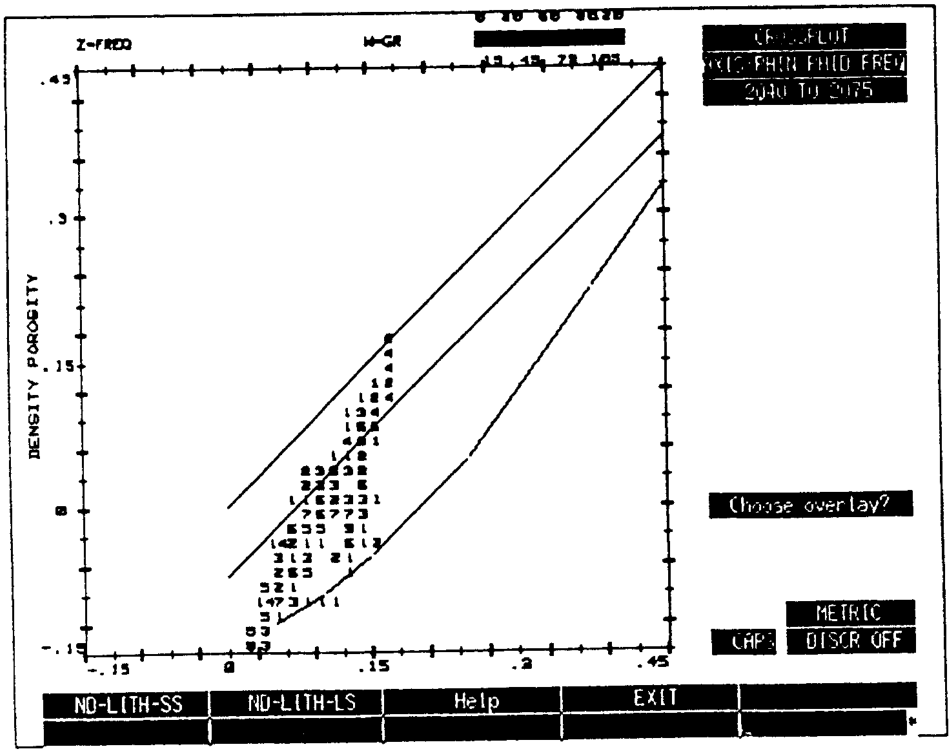

Figure 2a.

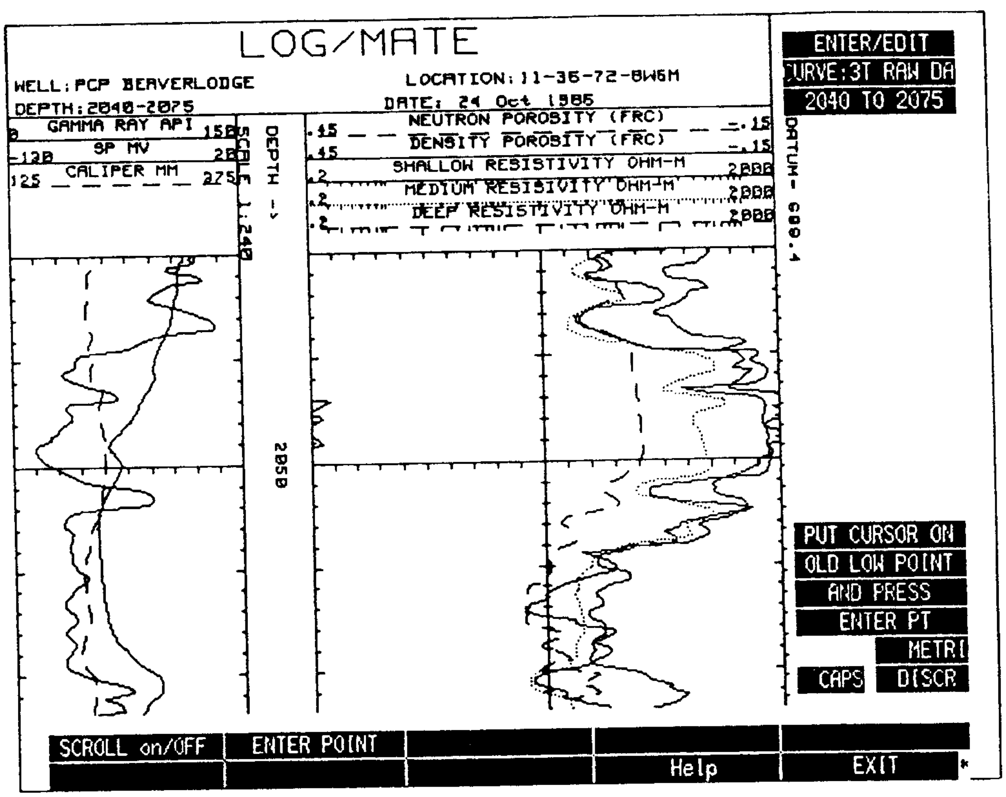

Figure 2b.

FIGURE 3 - ALGORITHM : SWbvw

ALGORITHM

```
PHItbvw = PHItbvw/100   ! ALGORITHM TO CALCULATE SW BY BULK VOLUME WATER  METHOD
PHIebvw = PHIebvw/100   ! NOTE : POROSITIES MUST COME FROM PHIbvw  ALGORITHM
VSH = VSH/100
CONST1 = 100(100-PHIDDC)*(100-PHINSH)/(100-PHIDSH)                    ! PHINDC
CONST2 = ((CONST1*PHIDSH-PHIDDC*PHINSH)/(CONST1-PHIDDC))/100         ! BVWSH
CONST3 = (CONST2*M)*RSH/A                                             ! RWSH
IF PHItbvw>0.02          ! STOPS THOSE NASTY DIVIDE BY ZERO THINGS                K
RESULT2 = VSH*CONST2/PHItbvw                                          ! BVW
RESULT3 = A*RW@FT*CONST3/(PHItbvw*M)/(CONST3-RESULT2*(RW@FT-CONST3))    ! RO
RESULT3 = MAX(RESULT3,0.1)
RESULT4(RESULT3/RESDc2)^(1/N)
ELSE                     ! ELSE WE HAVE NO POROSITY SO DON'T  SWEAT SW
RESULT4 = 1              ! JUST CALL IT 100 % AND LET IT GO AT THAT
END IF
IF PHIebvw>0.02          ! SAME STORY ON THE ZERO'S
RESULT3 = (PHItbvw/PHIebvw)*(RESULT4-RESULT2)
ELSE
RESULT3 = 1
END IF
PHIebvw = PHIebvw*100
PHItbvw = PHItbvw*100
VSH = VSH*100
IF ?TRACE
TRACEsw = 4              ! 4 IS BULK VOL WAT IN WATER SAT CODE TABLE
END IF
SWtbvw = 100*RESULT4
SWebvw = 100*RESULT3
```

FIGURE 4 - ROUTINES : KEN'S HALFWAY

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ALGORITHM NAME	PUT RESULT IN
VSHgr	VSH
VSHbal	
PHINc	PHI
PHIbal	PHINc
PHIDc	
PHIxcl	PHI
PHIbal	
SXOs	SW
SWsmth	SXO
SWs	SW
SWsmth	
RHOma	
PHIsec	
MNlith	
VROCK3mn	
DCAL	
PERMp	PERM
fPHIxS	

Result of Function Expert System

The expert system recommends the computation:

```
histo_K0
histo_K100
VSHpot
vsh_min
vsh_bal
const_RHOMA
RHOW_PHicoreDensxplot
PHIDSH_PhinPhidxplot
PHINSH_PhinPhidxplot
PHIxss
const_PHIMAX
PHIbal
const_DNTRIG
const_DTTRIG
const_GRTRIG
const_NTTRIG
const_RTTRIG
const_CTRIG
coal_trig
const_ATRIG
anhy_trig
const_GTRIG
gyp_trig
const_STRIG
salt_trig
A_PhicoreFFxplot
const_RHOMA
head_FT
RWatFT_from_PW
SWwssat_balsat_smooth
PHIDSH_PhinPhidxplot
RHOma
DELTSH_DeltPhidxplot
DELTW_DeltPhicorexplot
DELTma
VROCK2mid
```

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Figure 4a.

name: volume_of_shale_GR

parameters: GR0, GR100
results: none
pre-conditions: exists_GR, te_urn_not
post-conditions: bh_corr
type: or
body: vshGR_fld, vshGR_fld_not

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Figure 5.

A sample function frame in the network. Names in the slots are names of other frames.

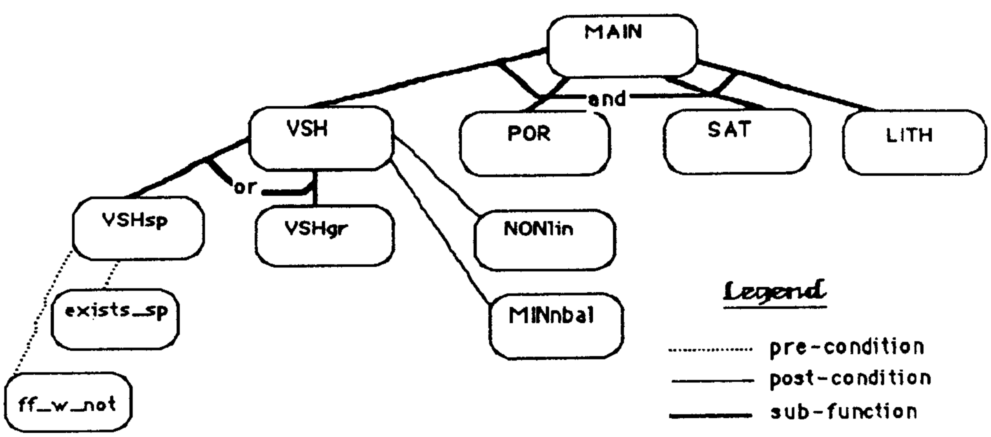

Figure 6.

Our knowledge base can be seen as a complex network of function nodes connected by arcs representing various relationships. The sub-function relation specifies an underlying and/or/any/all tree.

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APPENDIX

Note: The questions as shown here represent what is described as log response evaluation in the literature.

A. LITHOLOGY

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Logs (present)	Preconditional Algorithms	Questions	Lithology Assessed
gamma ray	draw baseline	vsh >= 40%?	shale
gamma ray	draw baseline	vsh < 40%?	sandstone limestone dolomite
resistivity density	do Hingle plot 1	rm < 2.68g/cc?	sandstone
resistivity density	do Hingle plot 1	2.68 <= rm < 2.70g/cc?	sandstone limestone
resistivity density	do Hingle plot 1	2.70 <= rm < 2.74g/cc?	limestone
resistivity density	do Hingle plot 1	2.74 <= rm < 2.83g/cc?	limestone dolomite
resistivity density	do Hingle plot 1	2.83 <= rm < 2.88g/cc?	dolomite
resistivity sonic	do Hingle plot 2	delta t matrix <= 44sec?	dolomite
resistivity sonic	do Hingle plot 2	44sec < dt ma <= 48sec?	limestone dolomite
resistivity sonic	do Hingle plot 2	48sec < dt ma <= 51sec?	limestone
resistivity sonic	do Hingle plot 2	51sec < dt ma <= 57sec?	sandstone limestone
resistivity sonic	do Hingle plot 2	deltma t matrix > 57sec?	sandstone

Properties

resistivity neutron	do Hingle plot 3	-6 < phi matrix <= -4?	dolomite
resistivity neutron	do Hingle plot 3	-4 < phi matrix <= -1?	limestone dolomite
resistivity neutron	do Hingle plot 3	-1 < phi matrix <= +1?	limestone
resistivity neutron	do Hingle plot 3	+1 < phi matrix <= +3?	sandstone limestone
resistivity neutron	do Hingle plot 3	phi matrix > +3?	sandstone

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B. TRACE ELEMENTS

Logs (present)	**Preconditional Algorithms**	**Questions**	**Trace Elements Assessed**
gamma ray uranium curve thorium curve potassium curve	---	GR show shale, U > 5ppm, THOR <= 8ppm and POTA <= 2%?	sandstone limestone dolomite uranium
thorium curve potasium curve	---	THOR > 8ppm and POTA >2%?	shale

C. FORMATION FLUIDS

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Logs (present)	Preconditional Algorithms	Questions	Formation Fluid Assessed
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD increasing, and vsh increasing?	gas
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD increasing, and vsh constant?	gas
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD increasing, and vsh decreasing?	gas oil
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD constant, and vsh increasing?	gas
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD constant, and vsh constant?	gas
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD constant, and vsh decreasing?	gas oil
RESD GR density porosity neutron porosity	---	Approaching crossover, RESD increasing, constant, and decreasing	fresh water salt water
density porosity neutron porosity	---	PHIN at least 4pu < PHID?	crossover gas

resistivity density porosity neutron porosity	---	PHIN < 3pu larger than PHID and 10 < vsh <=20 or PHID < 6pu larger than PHID and 20 < vsh <=40	approaching crossover
resistivity density porosity neutron porosity	---	Approaching crossover and RESD increasing?	gas oil
resistivity density porosity neutron porosity	---	Approaching crossover and RESD decreasing?	fresh water salt water
GR density porosity neutron porosity	---	Approaching crossover and vsh increasing?	gas
GR density porosity neutron porosity	---	Approaching crossover and vsh constant?	gas
GR density porosity neutron porosity	---	Approaching crossover and vsh decrease?	fresh water salt water gas oil
SP	---	SP has positive deflection?	fresh water gas oil
SP	---	SP has negative deflection?	salt water gas oil

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A. VOLUME OF SHALE COMPUTATIONS

Logs (present)	**Hole Condition**	**Lithology** (not allowed)	**Trace Elements** (allowed)	**Trace Elements** (not allowed)
spectral gamma ray	---	---	---	---
gamma ray	---	---	feldspar	uranium
gamma ray	---	---	---	uranium
density porosity neutron porosity	1 1 or 2	dolomite	---	pyrite feldspar
sp	---	limestone dolomite	---	---
density porosity sonic	1 1, 2, or 3	---	---	pyrite
none		---	---	---

Vsh Computations

Formation Fluid (not allowed)	Computational Algorithms	Question/Algorithm	Postconditional Algorithms
---	spectral gamma ray potasium curve	---	vsh minimum vsh balance
---	gamma ray borehole corrorrection non linear correction	---	" "
---	gamma ray borehole correction	---	" "
gas	density neutron cross	---	" "
---	bed thickness correction	Min of -40mv between SP sand and shale?/sp	" "
---	sonic density cross	---	" "
---	no vsh algorithm is appropriate	---	---

B. POROSITY COMPUTATIONS

Logs (present)	**Hole Condition**	**Complex Lithology** (allowed)	**Formation Fluid** (not allowed)
density neutron	1 1 or 2	limestone and/or dolomite	gas
density neutron	1 1 or 2	---	gas
density neutron	1 1 or 2	---	gas
density sonic	1 1, 2, or 3	---	---
neutron sonic	1 or 2 1, 2, or 3	---	gas
density	1	---	---
neutron	1 or 2	---	gas
sonic	1, 2, or 3	---	---
none		---	---

Porosity Computations

Questions	Vsh Calculated	Computational Algorithms	Postconditional Algorithms
---	yes	por density neutron cross complex lithology	porosity balance coal trigger anhydrite trigger gypsum trigger salt trigger
PHIN = PHID +- 3pu?	---	por density neutron cross shaly sand	" "
---	yes	por density neutron cross bulk volume water	" "
---	---	por sonic density cross Wyllie	" "
Vsh <= 15%? (from vsh calcs)	yes	por sonic neutron cross	" "
---	yes	por density	" "
---	yes	por neutron	" "
---	yes	por sonic Wyllie	" "
---	---	no porosity algorithm is acceptable	---

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C. **WATER SATURATION**

Logs (present)	**Hole Condition**	**Trace Elements** (not allowed)	**Formation Fluid** (not allowed)	**Questions**
resistivity density neutron	--- 1 1 or 2	pyrite	gas	bvw used?
resistivity	---	pyrite	---	Vsh <= 15%? (from vsh calcs)
resistivity	---	pyrite	---	---
resistivity	---	pyrite	---	Qv &CEC data available?
TDT	---	---	---	---
dielectric	---	---	---	---
none	---	---	---	---

A. VOLUME OF SHALE COMPUTATIONS

Logs (present)	**Hole Condition**	**Lithology** (not allowed)	**Trace Elements** (allowed)	**Trace Elements** (not allowed)
spectral gamma ray	---	---	---	---
gamma ray	---	---	feldspar	uranium
gamma ray	---	---	---	uranium
density porosity neutron porosity	1 1 or 2	dolomite	---	pyrite feldspar
sp	---	limestone dolomite	---	---
density porosity sonic	1 1, 2, or 3	---	---	pyrite
none		---	---	---

Vsh Computations

Formation Fluid (not allowed)	Computational Algorithms	Question/Algorithm	Postconditional Algorithms
---	spectral gamma ray potasium curve	---	vsh minimum vsh balance
---	gamma ray borehole corrorrection non linear correction	---	" "
---	gamma ray borehole correction	---	" "
gas	density neutron cross	---	" "
---	bed thickness correction	Min of -40mv between SP sand and shale?/sp	" "
---	sonic density cross	---	" "
---	no vsh algorithm is appropriate	---	---

B. POROSITY COMPUTATIONS

Logs (present)	**Hole Condition**	**Complex Lithology** (allowed)	**Formation Fluid** (not allowed)
density neutron	1 1 or 2	limestone and/or dolomite	gas
density neutron	1 1 or 2	---	gas
density neutron	1 1 or 2	---	gas
density sonic	1 1, 2, or 3	---	---
neutron sonic	1 or 2 1, 2, or 3	---	gas
density	1	---	---
neutron	1 or 2	---	gas
sonic	1, 2, or 3	---	---
none		---	---

Porosity Computations

Questions	Vsh Calculated	Computational Algorithms	Postconditional Algorithms
---	yes	por density neutron cross complex lithology	porosity balance coal trigger anhydrite trigger gypsum trigger salt trigger
PHIN = PHID +- 3pu?	---	por density neutron cross shaly sand	" "
---	yes	por density neutron cross bulk volume water	" "
---	---	por sonic density cross Wyllie	" "
Vsh <= 15%? (from vsh calcs)	yes	por sonic neutron cross	" "
---	yes	por density	" "
---	yes	por neutron	" "
---	yes	por sonic Wyllie	" "
---	---	no porosity algorithm is acceptable	---

Saturation Computations

C. WATER SATURATION

Logs (present)	**Hole Condition**	**Trace Elements** (not allowed)	**Formation Fluid** (not allowed)	**Questions**
resistivity density neutron	--- 1 1 or 2	pyrite	gas	bvw used?
resistivity	---	pyrite	---	Vsh <= 15%? (from vsh calcs)
resistivity	---	pyrite	---	---
resistivity	---	pyrite	---	Qv &CEC data available?
TDT	---	---	---	---
dielectric	---	---	---	---
none	---	---	---	---

Saturation Computations

Vsh Calculated	Porosity Calculated	Computational Algorithms	Postconditional Algorithms
yes	---	bvw method	sat balance & smooth
yes	yes	Archie method	" "
yes	yes	Simandou method	" "
yes	yes	Waxman-Smit method	" "
yes	yes	TDT method	" "
yes	yes	EPT method	" "
---	---	no saturation alg is appropriate	---

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D. LITHOLOGY COMPUTATIONS

Logs (present)	Hole Condition	Lithology (allowed)	Trace Elements (not allowed)	Formation Fluid (not allowed)
PED density sonic	1 1 1, 2, or 3	---	pyrite	---
density neutron sonic	1 1 or 2 1, 2, or 3	limestone and/or dolomite	pyrite	gas
density neutron sonic	1 1 or 2 1, 2, or 3	---	pyrite	gas
density sonic	1 1, 2, or 3	---	pyrite	---
density	1	---	pyrite	---
sonic	1, 2, or 3	---	---	---
none	---	---	---	---

Lithology Computations

Vsh Calculated	Porosity Calculated	Matrix Density	Matrix Travel Time	Computational Algorithms
yes	yes	densma calc	deltma calc	UMA method
yes	yes	densma calc	deltma calc	CNL-DEN method
yes	yes	densma calc	deltma calc	m and n method mn calc
yes	yes	densma calc	deltma calc	midplot method
yes	yes	densma calc	---	vrockd method
yes	yes	---	deltma calc	vrocks method
---	---	---	---	no lithology algorithm is appropriate

ALGORITHMS	LOG/MATE ALGORITHMS	PARAMETERS corresponding to ALGORITHMS
spectral gamma ray potasium	VSHpot	K0, K100
gamma ray	VSHgr	GR0, GR100
density neutron cross	VSHxnd	PHIDSH, PHINSH or PHINSH, PHIDSH, RHOMA, RHOW
sp	VSHsp	SP0, SP100
sonic density cross	VSHxsd	CDTSH, DELTMA, DELTSH, DELTW, RHOMA, RHOW, PHIDSH, PHISSH
borehole correction	BCORGR	MWT, BITZ
non-linear correction	VSHc1	
bed thickness correction	bed_thick_corr	
vsh minimum	VSHmin	
vsh balance	VSHbal	
por density neutron cross complex lithology	PHIxcl	RHOMA, RHOW, PHIDSH, PHINSH
por density neutron cross shaly sand	PHIxss	RHOMA, RHOW, PHIDSH, PHINSH
por density neutron cross bulk volume water	PHIbvw	PHIDDC, PHIDSH, PHINDC, PHINSH
por sonic density Wyllie	PHIxsd	CDTSH, DELTMA, DELTSH, DELTW, PHIDSH
por sonic neutron cross	PHIxsn	CP, CDTSH, DELTMA, DELTSH, DELTW, PHINSH, PHISSH
por density	PHIdens	RHOMA, RHOSH, RHOW, KD or PHIDSH, RHOMA, RHOW
por neutron	PHIneut	KD, PHINSH
por sonic Wyllie	PHISwyl	CDTSH, DELTMA, DELTSH, DELTW, KS
por balance	PHIbal	PHIMAX
coal trigger	coal_trig	DNTRIG, DTTRIG, GRTRIG, NTTRIG, RTTRIG, CTRIG
anhydrite trigger	anhy_trig	DNTRIG, DTTRIG, GRTRIG, NTTRIG, RTTRIG, ATRIG
gypsum trigger	gyp_trig	DNTRIG, DTTRIG, GRTRIG, NTTRIG, RTTRIG, GTRIG
salt trigger	salt_trig	DNTRIG, DTTRIG, GRTRIG, NTTRIG, RTTRIG, STRIG
Waxman-Smit method	SWws	A, RHOMA, FT, RWatFT
Simandou method	SWs	A, M, N, RSH, RWatFT
Archie method	SWa1	A, M, N, RWatFT
bvw method	SWbvw	A, BVWSH, RSH, RWatFT
TDT method	SWtdt	SIGMAMA, SIGMAW, SIGMAH, SIGMASH
EPT method	SWept	ATTN, BHT, BHTDEP, BVWSH, SUFT, TMP
saturation balance & smooth	SWsmth	
UMA method	UMA	UF, RHOMA1, RHOMA2, RHOMA3, UMA1, UMA2, UMA3
CNL-DENS method	CNL_DENS	
M and N method	VROCK3mn	MLITH1, MLITH2, MLITH3, NLITH1, NLITH2, NLITH3
MN calculation	MNlith	DELTSH, DELTW, RHOW, PHIDSH, PHINSH
midplot method	VROCK2mid	DELTMA1, DELTMA2, DELTMA3, RHOMA1, RHOMA2, RHOMA3
vrockd method	VROCK2d	DENS1, DENS2
vrocks method	VROCK2s	DELT1, DELT2
densma calculation	RHOma	PHIDSH
deltma calculation	DELTma	DELTSH, DELTW

PARAMETER ASSIGNING METHODS

A PhicoreFFxplot
A PhiResxplot
stand A
const ATRIG
stand ATRIG
stand ATTN
head BHT
head BHTDEP
head BITZ
BVWSH PhinPhidxplot
deriv BVWSH
stand BVWSH
CDTSH PhisPhicorexplot
CDTSH DeltPhidxplot
CDTSH GrDeltxplot
stand CDTSH
CP PhisPhicorexplot
CP DeltPhidxplot
CP GrDeltxplot
stand CP
const CTRIG
stand CTRIG
stand DELT1
stand DELT2
const DELTMA
stand DELTMA
stand DELTMA1
stand DELTMA2
stand DELTMA3
DELTSH DeltPhidxplot
DELTSH GrDeltxplot
stand DELTSH
DELTW DeltPhicorexplot
const DELTW
stand DELTW
stand DENS1
stand DENS2
const DNTRIG
stand DNTRIG
const DTTRIG
stand DTTRIG
head FT
histo GR0
stand GR0
histo GR100
histo GR100rd
stand GR100
const GRTRIG
stand GRTRIG
const GTRIG

Continued

N RIcoreSwxplot
N PhiResxplot
stand N
stand NLITH1
stand NLITH2
stand NLITH3
const NTTRIG
stand NTTRIG
PHIDDC PhinPhidxplot
deriv PHIDDC
stand PHIDDC
PHIDSH PhinPhidxplot
PHIDSH GrPhidxplot
stand PHIDSH
const PHIMAX
stand PHIMAX
PHINDC PhinPhidxplot
deriv PHINDC
stand PHINDC
PHINSH PhinPhidxplot
PHINSH GrPhinxplot
stand PHINSH
PHISSH DeltPhidxplot
PHISSH GrDeltxplot
stand PHISSH
const PHIMAX
stand PHIMAX
const RHOMA
stand RHOMA
stand RHOMA1
stand RHOMA2
stand RHOMA3
stand RHOSH
RHOW PhicoreDensxplot
const RHOW
stand RHOW
stand RSH
const RTTRIG
stand RTTRIG
RWatFT from PW
RWatFT from DST
RWatFT from WC
RWatFT from deriv
RWatFT from stand
const SIGMAH
stand SIGMAH
SIGMAMA TDTPhicorexplot
const SIGMAMA
stand SIGMAMA
stand SIGMASH

K

stand GTRIG
histo K0
stand K0
histo K100
stand K100
stand KD
stand KS
M PhicoreFFxplot
M PhiResxplot
stand M
stand MLITH1
stand MLITH2
stand MLITH3
head MWT

stand SIGMAW
histo SP0
stand SP0
histo SP100
stand SP100
const STRIG
stand STRIG
head SUFT
const TPM
stand TPM
deriv UF
stand UF
stand UMA1
stand UMA2
stand UMA3

K

Project Manager (D&S Knowledge Systems Inc.)

L. (Lance) Pepperdine graduated from the University of Alberta with a B.Sc. in Chemical Engineering. He was employed by Consolidated Mining and Smelting in a varied career in research and development in mining, fertilizer technology, and mineral separation. Other duties with Cominco included project management on construction and startup of a urea plant. He later worked for the production research group of Imperial Oil in tar sands and heavy oil research, as well as tight hole work in conventional oil and gas plays. He followed this with work in Esso's Systems and Computer Services, and with project management, design, startup, and operation of the Redwater fertilizer plant.

Lance later joined the Petroleum Resources Branch of British Columbia as reservoir engineer/computer specialist, dealing primarily with log analysis and reserves determinations for the province. He has also been Engineering Manager for a small independant oil company and a consulting engineer to the oil industry. Lance is a director of D&S knowledge Systems Inc. a wholly owned subsidiary of D&S Petroleum Consulting Group Ltd.

K

Programmer/Analyst (D&S Knowledge Systems Inc.)

D.E. (Dave) Jaques received a B.Sc. in Electrical Engineering from the University of Calgary. He has worked as a logging engineer and design engineer for an independant Canadian well logging service company, and as a software designer and programmer for the same company. For the last four years he has been project leader for the LOG/MATE ESP system design and implementation group at D&S. Dave's interests lie in data base design, graphics, and human interface issues on desktop micro computers. Dave is the architect of the data base and prime designer of the interface to the functions in the expert system building tool.

Programmer/Analyst (D&S Knowledge Systems Inc.)

K.W. Edwards has experienced a steadily advancing career in well logging, log analysis,and research, culminating as general manager and officer of an independant Canadian well logging company. He has consulted to the oil industry in computer aspects of log analysis and finally joined D&S as senior programmer/analyst on the LOG/MATE ESP project. His interests include programming languages and operating systems, fourth generation languages, interactive graphics, and micro computer practical applications. Ken is the person responsible for the algorithm processor and the report generator as well as many of the myriad facets of the expert system building tool.

Programmer/Analyst (Alberta Research Council)

- L.A. (Lynn) Sutherland received a B.Sc.(Honours) in Computer Science from Queen's University. She was a research associate at Queen's and visiting scientist at MIT before joining the Alberta Research Council. Ms. Sutherland is an expert in UNIX, C, and IBM PC programming, and in software portability issues. She is interested in knowledge representation, distributed processing, parallel processing, and algorithm design. She has four years experience in design and development of a large, portable C program called Q'Nial, an interpretor for the programming lanquage Nial. Lynn is the architect of the inference engine and designer of the expert system for the project. Her knowledge in the design and control of large programming projects has been of great help to the project.

K Knowledge Engineer (Alberta Research Council)

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R.L. (Ron) Jakeman received a B.Sc. in Computer Science (a minor in Applied Mathematics) from the University of Calgary. Ron worked a number of years in the petroleum industry before joining D&S a year and a half ago. Since that time Ron has been involved in the design and implementation of the graphics and data communications portion of the LOG/MATE system.