
LOG ANALYSIS OF HEAVY OIL USING AN EXPERT SYSTEM

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ABSTRACT

This paper describes the interactive use of an expert log analysis system to evaluate a heavy oil well. The system's inference engine (EXPERT) was used to build a routine of algorithms for the analysis.

Each of the six functions of LOG/MATE ASSISTANT:

- database
- algorithm processor
- interactive graphics
- report generator
- data communications
- inference engine (EXPERT)

was used in the analysis. The data and results of the use of each function in the analysis of the heavy oil well is detailed.

The LOG/MATE ASSISTANT expert system is a completely interactive and totally data driven expert computer system. The user has complete control from the data input 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 primitives.

The expert system is a frame based organization of functions to reason about the log analysis problem. The EXPERT distinguishes between abstract functions, reasoned about by name, and algorithms, or syntactic representations for computing a function. While it reasons about abstract functions, it also executes algorithms to produce values to assist in the reasoning process for log analysis.

Algorithms have been modified from the standard log analysis routines to cope with the vagaries of unconsolidated heavy oil sands. The differences and adjustments to the expert system are noted.

INTRODUCTION

The goal of the LOG/MATE ASSISTANT project, a joint venture between D&S Knowledge Systems Inc. and the Alberta Research Council, 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 under the control of knowledge extracted from a petrophysics expert.

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:

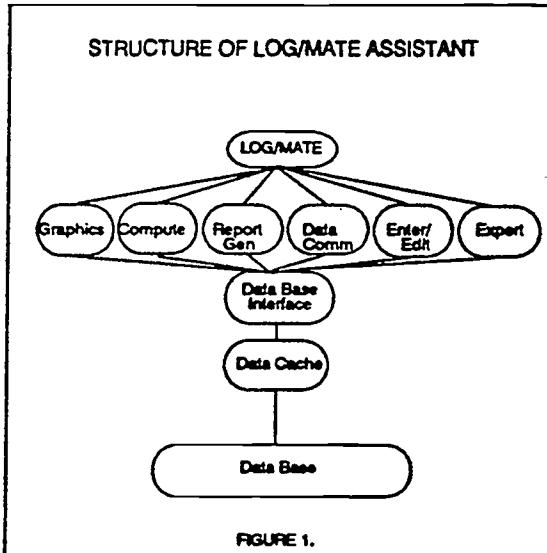
- 1. data communications
- 2. database and file manager
- 3. inference engine (EXPERT)
- 4. compute (algorithm processor)
- 5. interactive colour graphics
- 6. report generator

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.

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:



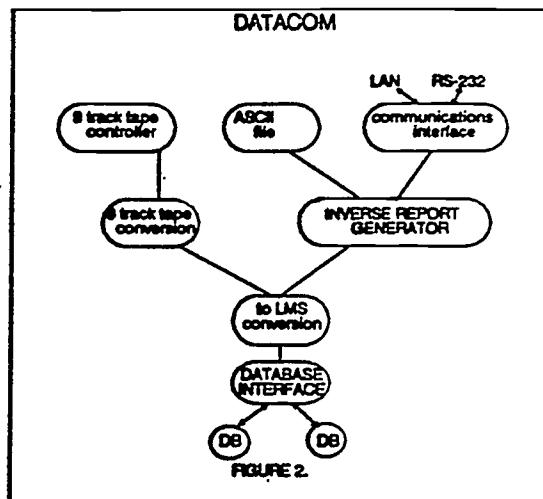
DATA COMMUNICATIONS

The data communication function relates to moving data into and out of the system. The functions provided are copy, select, backup, archive and restore facilities.

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

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. FIGURE 2 shows the organization of the Data Communications with respect to outside resources.

The information on the particular well that was analysed was contained on a 9 track magnetic tape. The information on the tape was decoded into the database from the Schlumberger LIS tape format. The bottom 210 meters was the zone of interest, and was selected and copied into the database.



DATABASE

The various logs selected from the Schlumberger tape for the zone of interest were placed in the database. The logs selected were GR,DENS and RESD.

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

The various logs are attached or related to each other as well as being related to the particular well. The attachments allow very rapid searches to be made by the program for required data, 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. It can be changed at any time by the user if there is a reason to do so.

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

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

INFERENCE ENGINE (EXPERT)

The data placed in the database from the magnetic tape of the heavy oil well was then examined by the EXPERT function of the system. The EXPERT used the frames of knowledge in the database to traverse the logic structure similar to that used by an petrophysicist in his analysis of a well. The database was examined to determine the logs and parameters available for use in the analysis. In its traversal of the knowledge base and the data contained in the data base it selected methods of calculating parameters used in calculating the values needed for the evaluation of shale, porosity, water saturation, hydrocarbon content and lithology of the formation. The results of the EXPERT evaluation is a routine for evaluating the well and is shown in FIGURE 3.

The inference engine is a frame based organization of functions that reasons about behaviour and generates algorithms for new functions. The system distinguishes between abstract functions, reasoned about by name, and algorithms, or syntactic representations of methodologies for computing a function. While the EXPERT 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 4. 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, 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 5 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. FIGURE 6 shows a sample of the explanation of why the EXPERT selected particular parameter selection methods and a particular way of analysing this well.

MATHEMATICAL PROCESSING

The routine for analysis of the heavy oil well, produced by the EXPERT, was then executed. The routine is a series of value selections, parameter calculations, graphical interpolations, and algorithmic methods executed in a particular order. The results of the running of the routine is the analysis of the well.

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. Routines prepared by the EXPERT function may be modified by the user or may be prepared without the aid of the EXPERT function.

INTERACTIVE COLOUR GRAPHICS

The results of the mathematical processing can be viewed graphically. The traces of the raw data and the computed or processed data for the heavy oil well are shown in FIGURE 7. A crossplot is also shown in FIGURE 8.

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 many times the size of the screen on the computer. This allows the user to prepare graphs and charts that can be plotted on paper many times the size of the CRT. The chart or graph may be viewed by scrolling to see 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.

REPORT GENERATOR

The results of the computations and analysis may be presented in tabular reports. The results of the analysis of this heavy oil well is shown in FIGURE 9.

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 you specify your page format - placement of headers, footers, titles, and text, etc. on the page. Numerous processing commands can be imbedded in reports to perform mathematical functions or to extract data elements from the database. In the case of LOG/MATE ASSISTANT standard reports, some quite complex, are delivered with the database.

BIBLIOGRAPHY

- 1. Sutherland, Lynn, Gamble, Ken; A Model for Generating Natural Functions. In Coupling Symbolic and Numeric Computing in Knowledge Based Systems
- 2. Crain, E.Ross, The Log Analysis Handbook. Penwell Books Volume 1: Quantitative Log Analysis Methods.

WELL
SUGGEST

The expert system recommends:

stand_COALDN
FIND COAL PHID?
stand_ANHYDN
FIND ANHY PHID?
VSHmin
histo_GR0
histo_GR100
VSHgr
VSHbal
stand_RHOMA
stand_RHOF
PHIdens
stand_PHIMAX
PHIbal
RSH_GrRtxplot
head_BHT
const_RW
stand_RWT
head_SUFT
RW@FT
SWs
SWsmth
1MM_sandstone

FIGURE 3.

ENTER/EDIT	ROUTINES : expert routine	
ALGORITHM NAME	SWITCH VA-LUE OR VAR	PUT RESULT IN
stand_COALDN	ON	
FIND COAL PHID?	ON	
stand_ANHYDN	ON	
FIND ANHY PHID?	ON	
VSHmin	ON	
histo_GR0	ON	
histo_GR100	ON	
VSHgr	ON	
VSHbal	ON	
stand_RHOMA	ON	
stand_RHOF	ON	
PHIdens	ON	
stand_PHIMAX	ON	
PHIbal	ON	
RSH_GrRtxplot	ON	
head_BHT	ON	
const_RW	ON	
stand_RWT	ON	
head_SUFT	ON	
RW@FT	ON	
SWS	ON	
SWsmth	ON	
1MM_sandstone	ON	

FIGURE 3a.

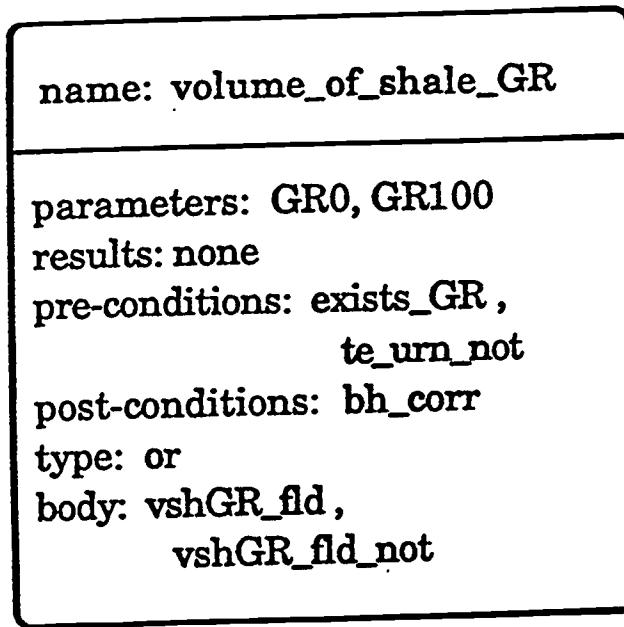


FIGURE 4.

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

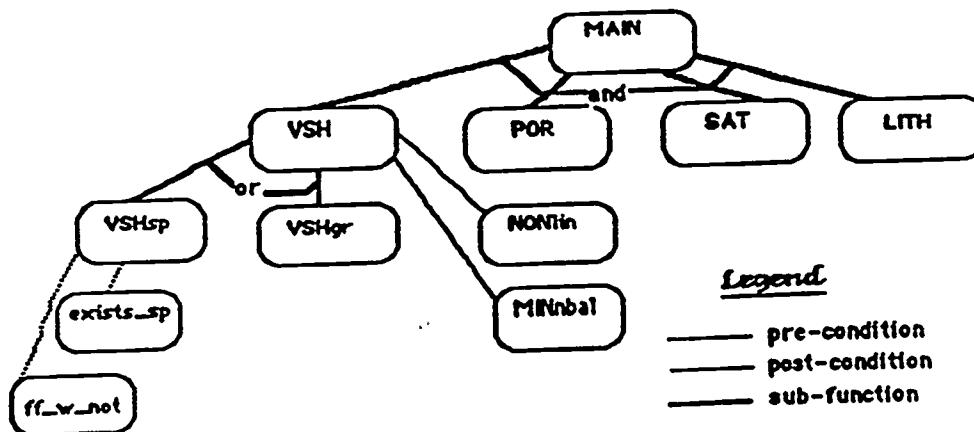


FIGURE 5.

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.

LOG/MATE

TAR ASSAY DETAIL

WELL : TAR TEST WELL PROJECT : IS FALSE DATE : Mon Nov 9
 LOCATION: TAR TEST WELL POOL : IS FALSE

PAGE

<u>DEPTH</u>	<u>POROSITY</u>	<u>WATER SAT</u>	<u>SHALE VOL</u>	<u>TAR WEIGHT</u>	<u>POROSITY X METRES</u>	<u>HYD X</u>
<u>metres</u>	<u>fraction</u>	<u>fraction</u>	<u>fraction</u>	<u>fraction</u>	<u>X METRES</u>	<u>X</u>
320.10	0.060	0.730	0.866	0.005	0.076	
320.40	0.065	0.737	0.856	0.007	0.131	
320.70	0.075	0.738	0.833	0.008	0.185	
321.00	0.052	0.732	0.885	0.005	0.245	
321.30	0.059	0.715	0.868	0.007	0.284	
321.60	0.122	0.682	0.729	0.016	0.323	
321.90	0.128	0.663	0.714	0.018	0.349	
322.20	0.073	0.669	0.837	0.010	0.368	
322.50	0.051	0.686	0.887	0.006	0.421	
322.80	0.119	0.708	0.736	0.014	0.492	
323.10	0.175	0.733	0.612	0.020	0.564	
323.40	0.195	0.742	0.567	0.022	0.592	
323.70	0.130	0.836	0.593	0.009	0.592	
324.00	0.121	0.641	0.731	0.018	0.592	
324.30	0.084	0.574	0.814	0.014	0.632	
324.60	0.053	0.520	0.883	0.010	0.696	
324.90	0.000	1.000	1.000	0.000	0.779	
325.20	0.000	1.000	1.000	0.000	0.864	
325.50	0.056	0.315	0.875	0.015	0.939	
325.80	0.299	0.305	0.336	0.036	1.027	
326.10	0.287	0.285	0.254	0.094	1.134	
326.40	0.300	0.239	0.251	0.106	1.251	
326.70	0.275	0.314	0.200	0.086	1.356	
327.00	0.286	0.355	0.180	0.085	1.440	
327.30	0.292	0.356	0.199	0.086	1.491	
327.60	0.281	0.323	0.268	0.087	1.534	
327.90	0.291	0.293	0.312	0.095	1.586	
328.20	0.287	0.285	0.363	0.094	1.613	
328.50	0.245	0.293	0.456	0.077	1.669	
328.80	0.208	0.300	0.537	0.063	1.785	
329.10	0.199	0.323	0.558	0.058	1.922	
329.40	0.231	0.368	0.487	0.064	2.059	
329.70	0.186	0.413	0.586	0.047	2.173	
330.00	0.257	0.472	0.393	0.061	2.238	

FIGURE 9.

LOGMATE/BEST

WELL: TPR TEST WELL
DEPTH: 300.0000-

LOCATION: TPR TEST WELL

510.0000

DATE: Mon Nov 9 1987

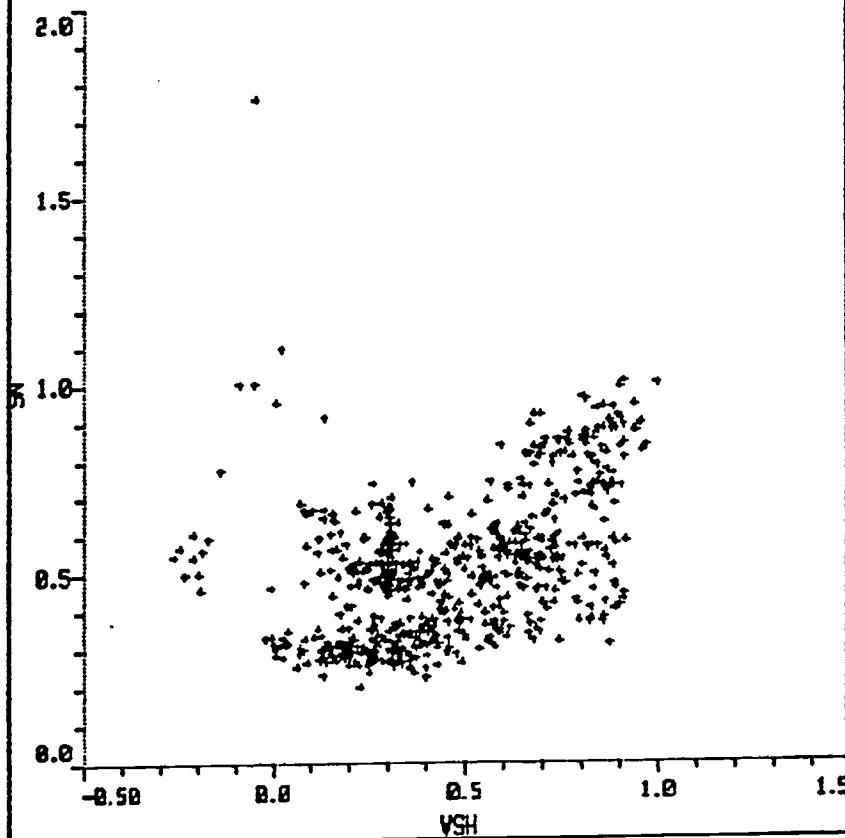


FIGURE 8.

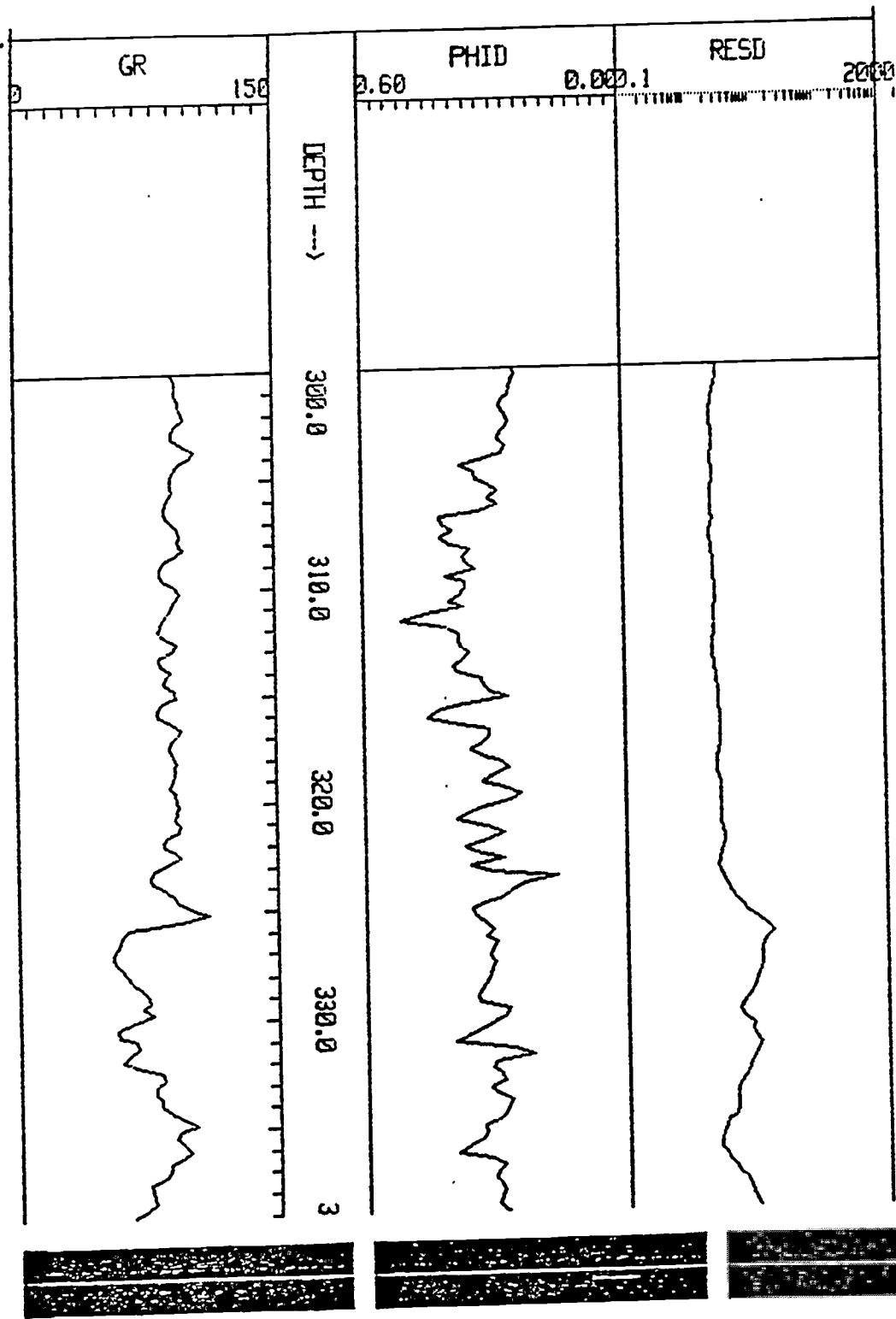


FIGURE 7.

~~get_algorithms~~ is true since all of its body, VSH, PHI, SW, LITH, are true.

~~get_pr_logs~~ is true since the pre-condition, ~~make_pr_logs_not~~, is true, and since all of its body, pr_logs1, pr_logs2, are true.

~~get_properties~~ is true since the pre-condition, ~~init_props~~, is true, and since all of its body, trace_elements², lithology², formation_fluid², should be ~~NULL~~.

~~get_npl_trigs~~ is true since all of its body, do_coal_trig², do_anhy_trig², do_gvns_trig, do_salt_trig, should be ~~NULL~~.

~~get_corrections~~ is true since all of its body, do_BCDRgr, bed_thick_corr, RESDc2, should be ~~NULL~~.

~~get_curves~~ is true since all of its body, create_DEWS_PHI0², create_PHIN, create_DELTA_PHIS, should be ~~NULL~~.

~~get_range~~ is true since ~~get_range~~ is a primitive.

FIGURE 6.

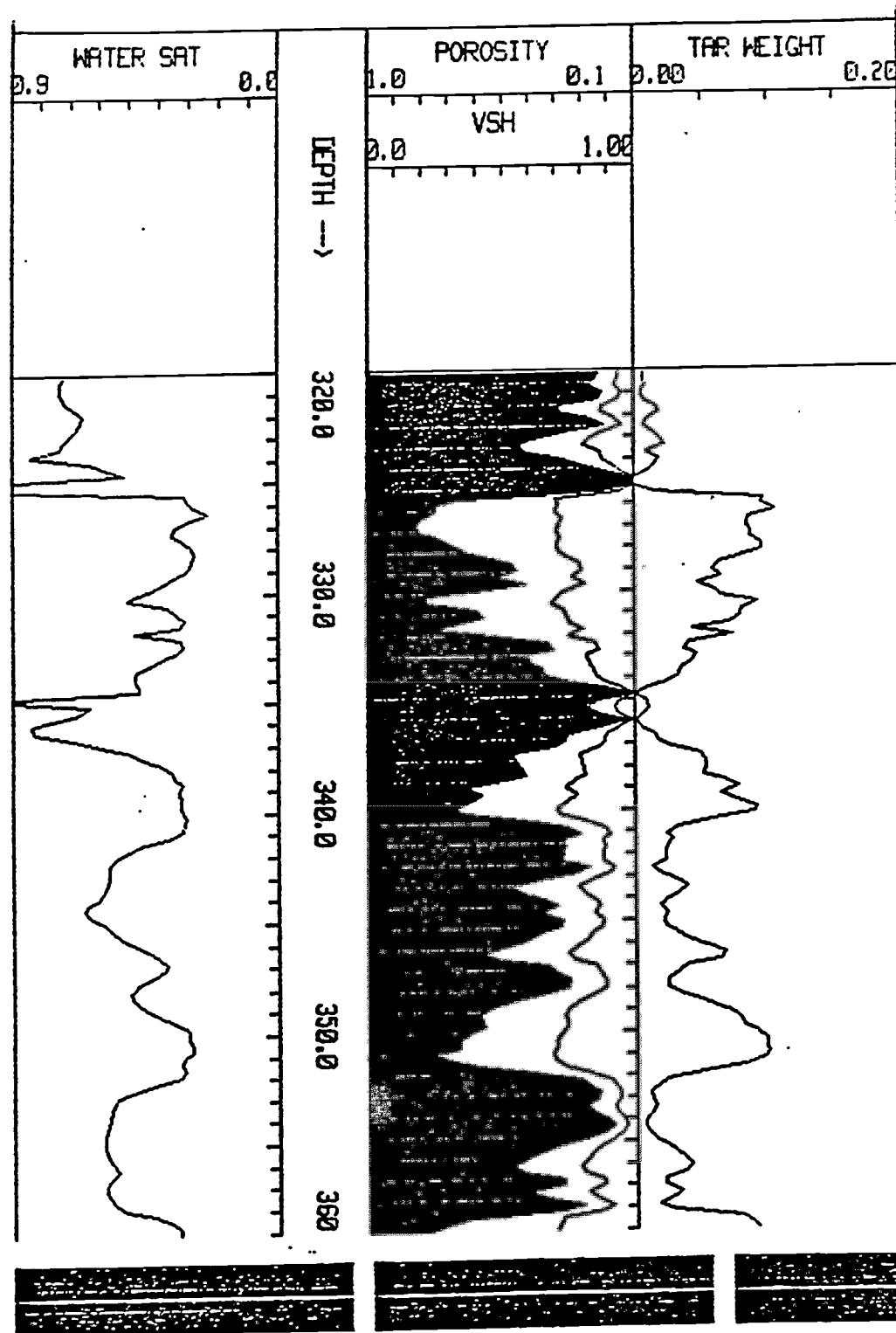


FIGURE 9a.