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GLOBAL, A NEW APPROACH TO COMPUTER-PROCESSED LOG INTERPRETATION

by

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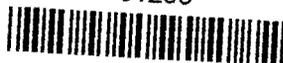
ABSTRACT

A new computer-processed log interpretation chain, GLOBAL, uses a structure independent of model and logging suite. An error model is defined relating tool measurements to petrophysical parameters such as porosity, lithology, and fluid saturation. Then, using a minimization routine, GLOBAL searches for the solution with the minimum error. This solution is considered the most probable answer.

A quality curve is presented indicating how well the answers fit the chosen model. The curve helps to determine if the model is inadequate, or if insufficient information is available to solve the interpretation problem.

The main advantages shown by the examples analyzed are:

- *Simultaneous use is made of all combination of logs, including experimental or recently introduced sensors.*
- *The approach works for very complex lithologies.*
- *It is adaptable to all kinds of models and local conditions.*



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INTRODUCTION

GLOBAL constitutes a new methodology for computer-processed log interpretation, transforming a set of borehole logging measurements into a set of formation evaluation answers, such as porosity, lithology and fluid saturations. In this manner it resembles other existing CPI programs (SARABAND* ⁽¹⁾, CORIBAND* ⁽²⁾, etc.). However, the new concept of GLOBAL offers a versatility of computation, choice of interpretation models and ease of utilizing new logging measurements that has been lacking in the past.

HISTORICAL BACKGROUND

Until recently, most major log evaluation programs were based on cross-plot techniques primarily using the Neutron-Density combination. In these programs, the computer reproduces, step by step, the classical "manual" interpretation process. This approach has the advantage of being easily understood by log interpretation specialists and allows the users to follow the logic of a program in terms of their own way of thinking.

Such techniques, however, have been outstripped by the present-day evolution of log interpretation in its effort to deal with the increasing complexity of formations in which oil and gas are sought, and the advent of new sensors and increasing multiplicity of models, developed to understand these formations.

An increasing number of versions, options, threshold parameters, etc., in log interpretation programs have been developed to cover a large range of special cases, increasing the difficulty of the log analysts' task. The existing programs remain valid in their principles, and give good results in most cases; however, they have become complex to control, and do not always make the best use of available information.

OBJECTIVES OF THE "GLOBAL" APPROACH

It was felt that a new approach to computer-processed log interpretation should be developed, pursuing the following objectives:

- to use all available information - log measurements, geological constraints, local knowledge.
- to seek results which make optimum use of this complex body of information.

- to have a strong potential for evolution, characterized by the easy introduction of new sensors and new interpretation models.
- to provide a powerful and human-engineered quality control of interpretation results.

In terms of computer techniques, the above goals require:

- use of n-dimensional rather than 2-dimensional cross-plot techniques.
- use of probabilistic concepts to handle the physical data available, with a view to obtaining the most probable solutions.
- the building of a flexible and modular software system, in which tools and models are separate plug-in elements.

STATUS OF THE GLOBAL CHAIN

Following the above concepts, a chain of computer programs has been designed, implemented and tested, and is in use in Schlumberger field computing centers. The results obtained so far confirm that these goals, for the most part, have been reached.

This paper describes the principles and applications of the GLOBAL method, and outlines its main advantages with field examples.

GENERAL PRINCIPLES

To illustrate the principles of the method, let us consider a dual mineral formation. The inputs of the GLOBAL program are for each sample, or level, of the well:

- all available environmentally corrected logs, which may be written in array notation:
- $$\underline{a}(\ddagger) = (\rho_b, \phi_N, t, R_{xo}, R_t, GR, SP), \quad (1)$$

and

- a set of "zoned" parameters:
R_w, clay parameters, mud characteristics, etc.

The outputs, or unknowns, in such a formation are:

$$\underline{x} = (\phi, V_{cl}, S_w, S_{xo}, \rho_{ma}) \quad (2)$$

TOOL RESPONSE EQUATIONS

The relationships between inputs and outputs can be expressed by a set of tool response equations, one equation

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(†) throughout the paper, arrays are *underlined*.

for each tool. For example, the density relationship may be expressed as:

$$\rho_b = \phi S_{x_0} \rho_{mf} + \phi (1 - S_{x_0}) \rho_h + V_{cl} \rho_{cl} + (1 - \phi - V_{cl}) \rho_{ma} \quad (3)$$

Using the array notations introduced in (1) and (2), the tool response equations may be written:

$$\begin{aligned} a_1 &= f_1(\underline{x}) \\ a_2 &= f_2(\underline{x}) \\ &\dots \end{aligned} \quad (4)$$

where \underline{a} , or (a_1, a_2, \dots) , is the set of inputs at a particular level, and f_i is the tool response function of the i^{th} tool type. It should be noted that the functions f_i may depend on variables other than x_1, x_2 , etc. These variables, such as ρ_{mf}, ρ_{ma} etc., have traditionally been called "zoned parameters" and are assumed to be constant within a given zone. Determining these parameters must be done prior to the application of GLOBAL.

Equations (4) must be solved in order to find an interpretation solution. In addition, a solution must comply with certain constraints delineating the likely domain of the results.

The system of equations (4) may be either *underdetermined* (less equations than unknowns) or *overdetermined*. In the first case, an infinite number of solutions may be consistent with the system; thus if there are no valid reasons to select any one of them, no interpretation can be performed. Therefore, throughout this paper we shall assume that the system is overdetermined, or at least balanced. Since there is no exact solution to an overdetermined system, we shall confine ourselves to looking for an approximate one. This is quite consistent with the fact that the tool response equations are only approximations to the physical reality, and that the logs are subject to dispersion, errors and statistics.

APPROXIMATE SOLUTION AND THE INCOHERENCE FUNCTION

An approximate solution, \underline{x} , of system (4) is one where the residuals, ϵ_i , defined for each tool by

$$\epsilon_i = a_i - f_i(\underline{x}) \quad (5)$$

are as small as possible. Combining all tool response functions and constraints, we can define an error function, $\Delta(\underline{a}, \underline{x})$, to be a weighted sum of the residuals, including additional penalty terms corresponding to non-satisfied constraints:

$$\Delta(\underline{a}, \underline{x}) = \sum_i \left(\frac{a_i - f_i(\underline{x})}{u_i} \right)^2 + \text{constraint penalties} \quad (6)$$

This function is called the *incoherence function*, since it expresses the lack of coherence between logs, results, response equations and constraints. In equation (6), u_i is the standard deviation of the error distribution arising from the i^{th} tool response equation and results from dispersion on the

log as well as from the response function itself. The incoherence function is explained in more detail in the next section.

GLOBAL METHOD

The basic principle of the method may be stated as follows: for a given set of logs \underline{a} , the GLOBAL method determines the unknown vector \underline{x} which yields the *minimum value* of the incoherence function $\Delta(\underline{a}, \underline{x})$. Under reasonable assumptions, it can be shown that the results obtained in this manner are the most probable ones. The GLOBAL method is thus a maximum likelihood method, finding for a set of log responses the most probable log interpretation using all logs and their responses.

GLOBAL CHAIN

The practical implementation of the GLOBAL method requires a sequence of operations, performed under the control of the log analyst; some of these operations are manual, others are partly or fully automatized. The main functions performed are:

- environmental corrections of logs.
- computation of error parameters, u_i .
- selection of the unknown answer array, $\underline{x} = (x_1, x_2, \dots)$, according to the formation interpretation model being used.
- selection of tool response equations, f_i .
- determination of zoned parameters.
- application of the GLOBAL method to compute the most likely values of the interpretation answer, \underline{x} , at each level.

QUALITY CONTROL

The GLOBAL chain provides the log analyst with a set of powerful quality control displays. These help him judge the results and diagnose remedial action in the case of inconsistency or error.

DETAILS OF THE GLOBAL METHOD

In general, the method may be applied to any set of logs and any set of unknowns, providing an appropriate GLOBAL model is defined. For the rest of this paper, we shall call:

- a *GLOBAL program*, any program based on the minimization, level-by-level, of an incoherence function. (Fig. 1)

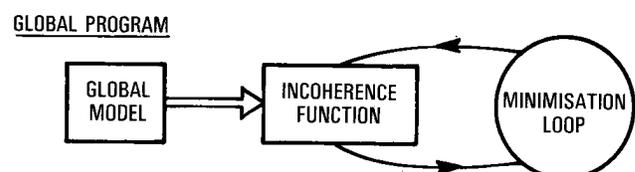


Fig. 1 — Structure of the GLOBAL Model.

- a **GLOBAL model**, the corresponding set of unknowns, tool response equations, etc. being input into the program.

We now describe in detail the various constituents of a GLOBAL model.

INPUTS

As before, $\underline{a} = (a_1, a_2, \dots)$ is the set of log readings to be used by the GLOBAL program. In general, \underline{a} is a set of environmentally corrected logs, but additional corrections may be necessary, for example shoulder bed and invasion corrections.

Examples of inputs are:

$$\underline{a} = (R_{LLd}, R_{LLs}, R_{ILD}, R_{MSFL}), \text{ as used in the } R_t \text{ GLOBAL program (RTGLOB)}$$

$$\underline{a} = (\rho_b, \phi_N, t, R_t, R_{x0}, GR, SP), \text{ as used in the Reservoir Interpretation GLOBAL program (RIG)}$$

LOG DISPERSION

The acquisition process leading to \underline{a} introduces many sources of error. These include:

- dispersion in the measurement apparatus (sensor, electronics, ...)
- dispersion in the raw data corrections (surface acquisition)
- dispersion in the environmental corrections (pre-interpretation software)

For each input a_i , we write σ_i for the standard deviation of the error distribution of the acquisition process. If the errors are asymmetric (positive and negative errors having different amplitudes), we use two dispersion coefficients: σ_i^- for negative errors (log reading too low) and σ_i^+ for positive errors (log reading too high). This often occurs with pad tools, where pad application problems yield errors mainly in one direction.

UNKNOWNNS

\underline{x} is the array of unknowns to be determined by the GLOBAL program. Examples are:

$$\underline{x} = (R_t, R_{x0}, d_i) \quad \text{in RTGLOB}$$

$$\underline{x} = (\phi, V_{cl}, S_{x0}, S_w, \rho_{min}) \quad \text{in the dual mineral model}$$

$$\underline{x} = (\phi, V_{cl}, S_{x0}, S_w, \rho_h) \quad \text{in shaly sands.}$$

x_1, \dots, x_n should correspond to the variable petrophysical characteristics of the formation. In order to maintain the overdetermination of the system, \underline{x} should have no more components than \underline{a} .

TOOL RESPONSE DISPERSION

Like the logs, the tool response equations are subject to dispersion. The error in an equation $a_i = f_i(\underline{x})$, is the difference between the two parts, assuming that both the log a_i

and the results \underline{x} are correct. Let the standard deviation of such an error be τ_i . τ_i may be caused by a combination of the following factors:

- the formulae f_i are simplifications of complex physical phenomena (e.g. Archie, Wyllie equations, etc.).
- some zoned parameters may be erroneously selected.
- there exist hidden parameters, which represent variable characteristics of the formation effecting the logs, but which are not taken into account in the vector \underline{x} . These would include such things as textural parameters which affect the acoustic and the electrical properties of the formation; or special minerals, assumed to be absent.

Since the errors on the response equations may vary with the formation encountered, τ_i must be a function of \underline{x} . For example, results from the sonic equation become less accurate in gas-bearing and unconsolidated formations.

TOTAL ERROR

The total error of the system (logs and response functions) was defined as u_i . Assuming the acquisition and tool response errors are independent, the standard deviation of the total error is given by:

$$u_i^2 = \sigma_i^2 + \tau_i^2 \quad (7)$$

CONSTRAINTS

The general type of constraint we consider is of the form:

$$g_j(x) \geq 0, \quad (8)$$

where j is the constraint number, and $g_j(x)$ is a function involving the unknowns (x_1, x_2, \dots), as well as some log analyst chosen constants, but no log measurements. As with the tool response functions, constraints may also have dispersion, τ_j . Four types of constraints are presently used:

(a) Mathematical Constraints

These constraints are rigid and allow no dispersion; they result from the very definition of the unknowns. Examples are:

$$0 \leq \phi \leq 1,$$

$$0 \leq V_{cl} \leq 1.$$

(b) Geological Constraints

These express approximate relations between the unknowns, caused by geological or physical laws. These expressions are subject to dispersion. For example.

$$S_w \leq S_{x0}$$

$$\phi \leq \phi_{max} (1 - V_{cl})^{1.5}$$

(c) Local Constraints

These express a priori knowledge of the likely results, and are set by the log analyst. Thus we may impose a maxi-

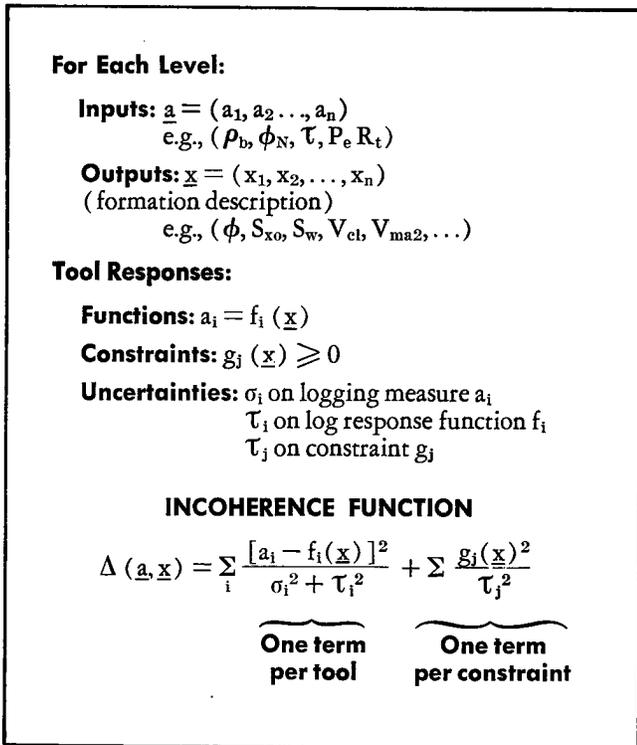


Fig. 2 — Summary of GLOBAL Model and Incoherence Function.

mum clay content, a minimum water saturation, a porosity range, etc.

(d) Continuity Constraints

Continuity constraints express the fact that the results cannot have a better vertical resolution than the logs themselves. Their dispersions are set accordingly to prevent too much discontinuity in the computed results.

MINIMIZING THE INCOHERENCE FUNCTION

Fig. 2 summarizes the inputs and outputs of the GLOBAL method and incoherence function. A GLOBAL program essentially minimizes the incoherence function, $\Delta(\underline{a}, \underline{x})$, resulting from the associated model, with respect to \underline{x} . A trial-and-error approach is used. An initial value, \underline{x}_0 , is computed using a heuristic or quick-look interpretation; then after each step an intermediate result, \underline{x}_n , is computed. The next result, \underline{x}_{n+1} , is derived from \underline{x}_n by a "steepest descent" technique, (see Fletcher⁽³⁾ and Powell⁽⁴⁾). The successive iterations are stopped when a convergence criterion is satisfied. The flowchart of the GLOBAL method is shown in Fig. 3.

THEORETICAL LOGS

In the incoherence function above, we may write a_i^* instead of $f_i(\underline{x})$. a_i^* may be thought of as the theoretical log corresponding to unknowns \underline{x} and function f_i . In the control displays provided by the GLOBAL programs, a_i and a_i^* are displayed for comparison and quality control.

EXAMPLES OF GLOBAL MODELS

In this section, we briefly describe three of the GLOBAL Models that have been implemented.

- RTGLOB (R_t GLOBAL) Model
- RIG - Multimineral Model
- RIG - Dual Water/Waxman-Smiths Models.

RTGLOB MODEL

In this model the unknowns are given by:

$$\underline{x} = (R_t, R_{x_0}, d_1) \tag{9}$$

This is a step resistivity profile assuming no annulus or gradual evolution of the invasion depth. All available resistivity logs are used including any micro-devices, Laterologs, Induction logs, Spherically Focussed logs. Tool response equations employ the classical radial geometrical factor concept. For example:

$$R = J R_{x_0} + (1 - J) R_t \text{ for Laterologs} \tag{10}$$

$$C = G C_{x_0} + (1 - G) C_t \text{ for Induction logs,} \tag{11}$$

where G and J are, respectively, the radial geometrical and pseudo-geometrical factors of the tools, themselves functions

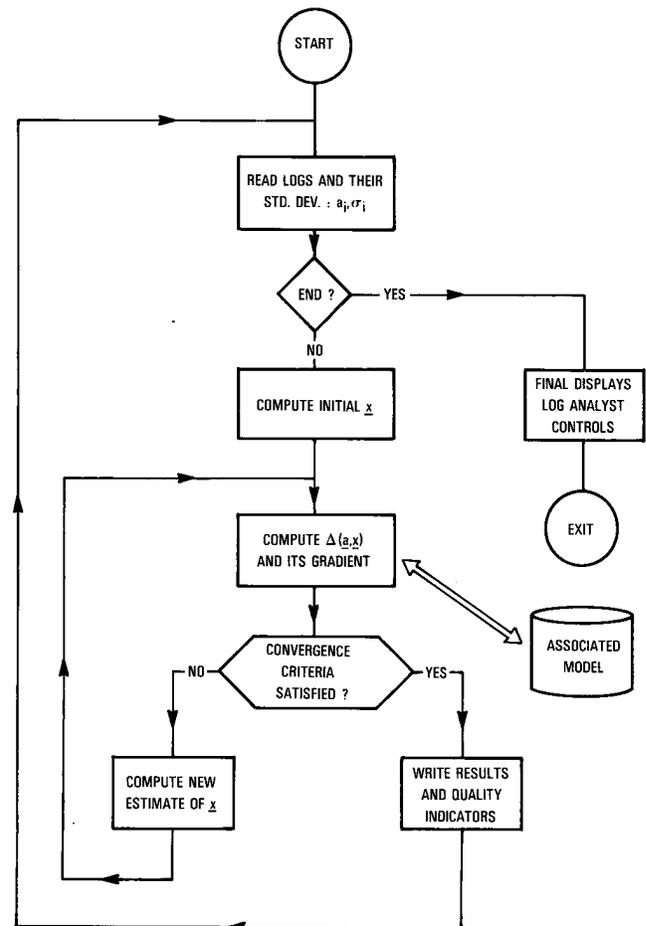


Fig. 3 — Flowchart of the GLOBAL method.

of R_t , R_{xo} and d_1 ^(5,6). Very few constraints are used, mainly mathematical ones. The geological constraint

$$\frac{R_{xo}}{R_t} \leq \frac{R_{mf}}{R_w}$$

is used when R_w is known.

MULTIMINERAL MODEL

The unknowns in this model are:

$$\underline{x} = (\phi, S_{xo}, S_w, V_{cl}, V_{ma1}, \dots, V_{ma6}) \quad (12)$$

where V_{ma1}, \dots, V_{ma6} are the bulk proportions of up to 6 minerals. These minerals may be standard ones (sands, carbonates, anhydrite, silt, . . .) or more unusual (siderite, glauconite, tuffites . . .). The log analyst chooses the minerals required for the interpretation.

All the presently available logs can be used as inputs:

- R_t and R_{xo} from RTGLOB
- Porosity Logs (Neutron, Formation Density, Sonic)

- Natural Radioactivity Logs (Gamma Ray, Natural Gamma Ray Spectrometry)
- Thermal Decay Time Log
- Electromagnetic Propagation Tool (Transit time, Attenuation)
- Litho-Density Tool (Density, Litholog)
- Spontaneous Potential

For each tool, a response equation has been established, using either standard formulae in the case of traditional logging tools, or new relationships obtained from recent studies for the newer tools. As special cases of the multi-mineral model, we have:

- *Dual Mineral Model* (Using only V_{ma1} and V_{ma2})
- *Shaly Sand Model* (Using mineral 1 for sand and mineral 2 for silt).

DUAL WATER⁷ AND WAXMAN-SMITS⁸ MODELS

For the Dual Water model, the unknowns are given by:

$$\underline{x} = (\phi_T, S_{xoT}, S_{wT}, S_{wb}, V_{ma1}, \dots, V_{ma6}) \quad (13)$$

where S_{xoT} , S_{wT} , are the water saturations pertinent to "total" porosity, and S_{wb} is the bound-water fraction of the total porosity. Minerals 1 to 6 may include standard and special minerals, silt, or various dry clay minerals. Again, any combination of these can be selected by the log analyst. The Waxman-Smits model uses a similar set of unknowns. The same logs are used as in the Multiminerall Model.

GLOBAL CHAIN DESCRIPTION

The minimization method, described above, constitutes the "heart" of the GLOBAL Method, but in practice, a complete processing sequence is necessary to implement the method. This sequence, partly manual, partly computerized, includes the following functions:

- Preinterpretation (depth matching, environmental corrections),
- Selection of the GLOBAL model to be used in each zone,
- Computation of the unknowns by minimizing the incoherence function,
- Quality control and diagnostics.

The flowchart of Fig. 4 shows these functions. On the right of each box is the name of existing programs written to perform some of these functions. Several of the operations remain, however, under the personal control of a log analyst. The main components of the present chain are LQDET (Log Quality Determination), RTGLOB (R_t GLOBAL) and RIG (Reservoir Interpretation by GLOBAL). Let us briefly review the elements of the flowchart.

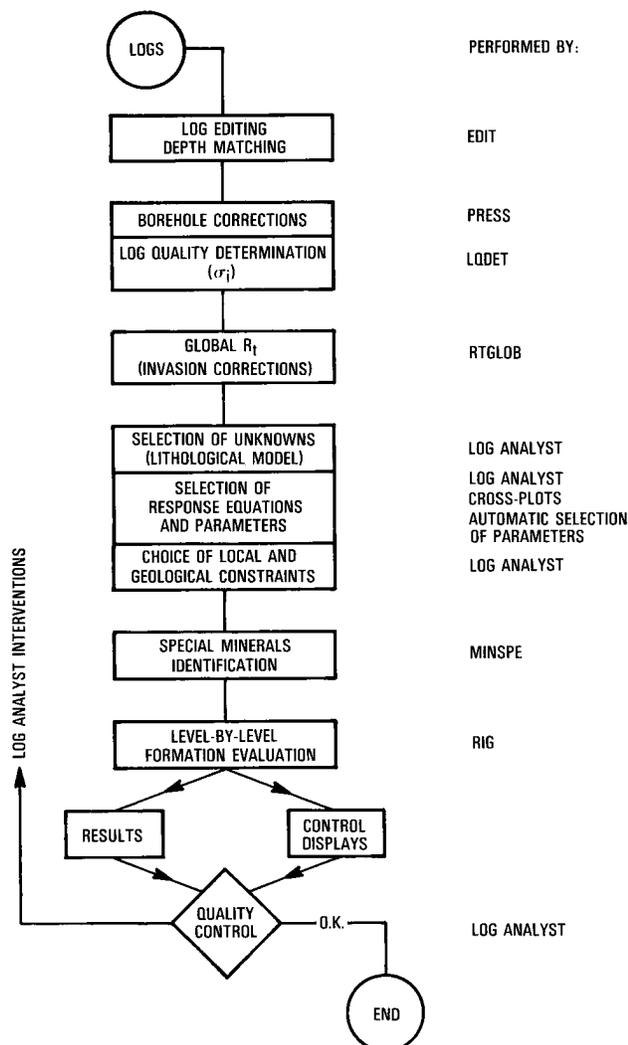


Fig. 4 — The chain of computation for a GLOBAL open-hole interpretation.

EDIT

This step is standard in any computer processed interpretation chain and is not affected by the GLOBAL method.

PRESS

This program performs the usual environmental corrections which remain unaffected by GLOBAL. Because these corrections are considered as a part of the log acquisition process, errors made during this phase combine with the measurement errors to contribute to total error. Acquisition uncertainties (σ_i) are consequently computed at this time.

LOG QUALITY DETERMINATION (LQDET)

For each logging measurement, error may result from many different factors, such as a caved hole, rugosity, the presence of mudcake, noise in the tool's electronics, nuclear statistics, cycle skipping, etc. If we assume these factors to be mutually independent, we can write:

$$\sigma_{\text{total}} = \sum \sigma_k^2 \quad (14)$$

where σ_k are the individual standard deviations resulting from each factor. In practice LQDET computes at each level, a certain number of environmental indicators, such as rugosity and mud cake thickness, which may affect the log readings. Then, for each tool, formulae describing the sensitivity of the measurement to these indicators permit a computation of each σ_k , giving finally, via equation (14), σ_{total} . The process of LQDET can be summarized by Fig. 5.

RTGLOB

RTGLOB is the first GLOBAL program of the chain. Here environmentally corrected values of resistivity logs are used to calculate the most consistent values of resistivities in the invaded and virgin formations.

SELECTION OF UNKNOWNNS FOR RIG

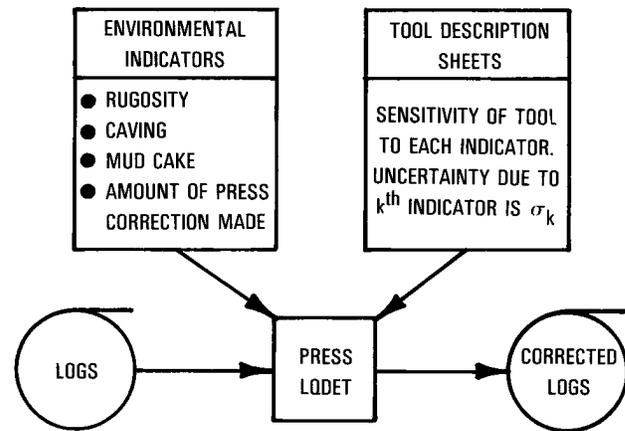
Depending on the interpretation model desired (multi-mineral, dual-water, etc.) and the lithology, a set of unknownns is chosen. These can vary in different zones and are selected by the log analyst from a set of options. In making his choice, the principle of overdetermination must be respected.

SELECTION OF RESPONSE EQUATIONS AND PARAMETERS

A number of equations has been established for each tool, related to each model option. The log analyst must select the response equation he desires, and choose the parameters in the tool response equations which are considered to be known. Traditional crossplots and related techniques are commonly used for this purpose, as they have been traditionally.

CHOICE OF LOCAL AND GEOLOGICAL CONSTRAINTS

These constraints are preset for each model but may be modified by the log analyst.



$$\sigma_{\text{TOTAL}}^2 = \sum_k \sigma_k^2$$

Fig. 5 — A schematic of log quality determination (LQDET).

IDENTIFICATION OF SPECIAL MINERALS (MINSPE)

This program flags the intervals where special non-permeable minerals are encountered, eg.: salt, trona, anhydrite, gypsum, potash and coal. The special minerals are detected when a set of conditions is satisfied by the logs. When RIG reads the corresponding flag, no minimization is performed and a special coding is displayed.

RIG (Level-by-level formation evaluation)

At this stage, all the ingredients of the RIG model have been gathered, except for the dispersions - τ_i . Each τ_i depends on the formation conditions, and is therefore a function of the unknown array \underline{x} . In RIG, for simplicity, $\tau_i(\underline{x})$ is computed from the initial estimate \underline{x}_0 , and redetermined from time to time if the minimization process carries the array, \underline{x}_n , too far from the initial estimate.

RIG outputs a standard presentation of the results as well as a number of quality control displays and statistics. First, the results are presented with standard coding, with distinct patterns used to represent the various minerals in the multiminerall option.

Second, a "control display" comparing the original and theoretical logs, \underline{a} and \underline{a}^* , is shown. Four curves are played back for each input log.

- the log itself, a_i , as read from the input file.
- two curves representing a confidence interval around the log, $a_i \pm u_i$; u_i is the standard deviation of the total error of the system, acquisition and tool response. This confidence interval is lightly shaded.
- the theoretical log, $a_i^* = f_i(\underline{x})$, where \underline{x} is the result found by the program. If a_i^* is found inside the shaded confidence interval, the corresponding log response equation is within tolerance.

Third, an indicator, called the *Reduced Incoherence* is derived, level by level, from the incoherence function. The

reduced incoherence should read everywhere less than 1 (except for isolated levels), indicating a reliable minimization.

Fourth, statistics are calculated to summarize the above quality controls, zone by zone, for the use of the log analyst.

QUALITY CONTROL

Quality Control is facilitated by the control displays and statistics provided by RTGLOB and RIG. After GLOBAL

processing, the log analyst can compare original and theoretical logs, and monitor the reduced incoherence.

If the reduced incoherence is too high (> 1), then the model has not been satisfied. Causes of this may come from a poor measurement, an incorrect function or constraint, a poor choice of a zone parameter, or an incorrect selection of \underline{x} . If the reduced incoherence is good (< 1), the tool response

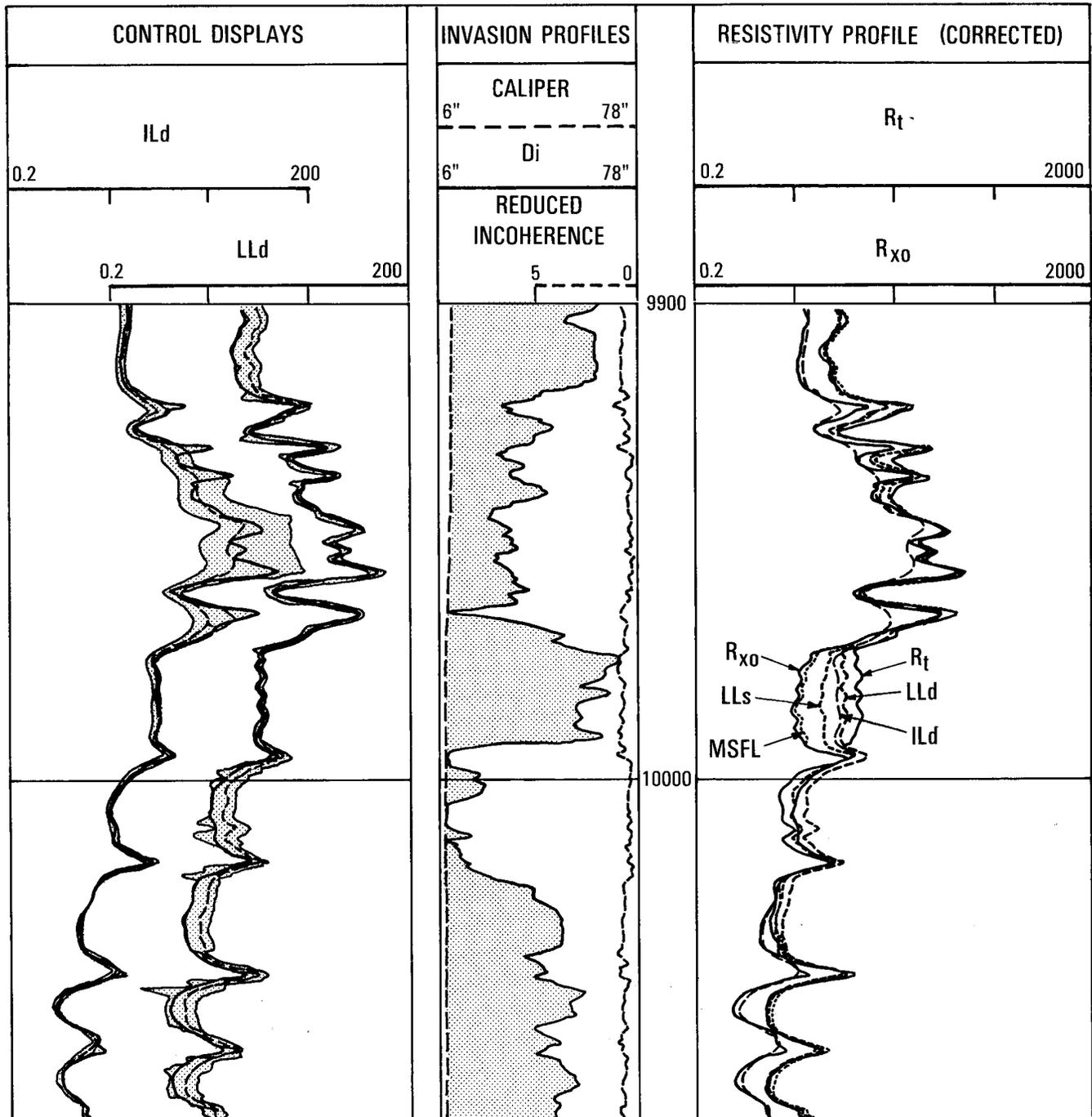


Fig. 6 — Example of R_t GLOBAL determination using four resistivity logs — ILd, LLd, LLs, MSFL to evaluate R_t , R_{xo} and d_i . In the "control displays" dashed curves are the original logs; solid curves are the theoretical logs after minimization of the incoherence function. Uncertainties on input logs are shown stippled.

equations, as well as the constraints, have all been satisfied by the results within acceptable tolerances.

It may happen that incorrect results satisfy log response equations and constraints. This occasionally happens when there are an insufficient number of active logs and constraints, and the system is therefore somewhat undetermined. When this situation is diagnosed, more information must be made available, by either adding logs and constraints, or reducing errors.

FIELD EXAMPLES

EXAMPLE OF GLOBAL R_t

Fig. 6 shows a result of processing using the RTGLOB program. The headings "Invasion profile" and "Resistivity profile" are the standard presentation. "Resistivity profile" displays the logs after environmental corrections together with the results, R_t and R_{xo} . "Invasion profile" displays graphically the amount of filtrate invasion (area between invasion diameter and caliper) and the quality curve - the reduced incoherence. Immediately we can see that the reduced incoherence is less than 1 throughout, implying that the results are consistent with the interpretation model.

In the section, "control displays", log analyst controls are shown for the deep Laterolog (LLd) and for the deep Induction (ILd) inputs. For both logs the dashed curve represents the original input log; the solid curve represents the theoretical log, calculated after minimizing the incoherence function; and the stippled area indicates the uncertainty on the log inputs. If the model fit is good, the solid theoretical curve should remain within the stippling. We can see that this is indeed the case. In this example, $R_w = .021 \Omega\text{m}$ and $R_{mf} = .052 \Omega\text{m}$ at total depth, so in water-bearing zones we would expect the Induction to be a better measure of R_t . The reservoir is a complex sequence of layers separated by resistive thin streaks. The thickness of the layers is such that the deep Laterolog is severely affected by shoulder beds, accounting for the large uncertainty on the deep Laterolog in zones 9995-10070 ft and 9900-9920 ft. In the higher resistivity areas, the Induction, being a conductivity measurement, has the higher uncertainty. RTGLOB weighs all these factors and computes the R_t and R_{xo} curves shown.

This combination of deep invasion, high and low resistivities and layering shows the need for both the Dual Laterolog and Induction for R_t determination.

EXAMPLE OF THE GLOBAL CHAIN - RTGLOB AND RIG

Fig. 7 shows another example of R_t GLOBAL processing - a preliminary stage in a complete GLOBAL chain of open-hole interpretation.

Fig. 8 shows the results of the reservoir interpretation made by GLOBAL (RIG). The presentation is traditional, but with the addition of the reduced incoherence curve, and the possibility of a more detailed lithological description. The lithology in this example is sand, silt and clay.

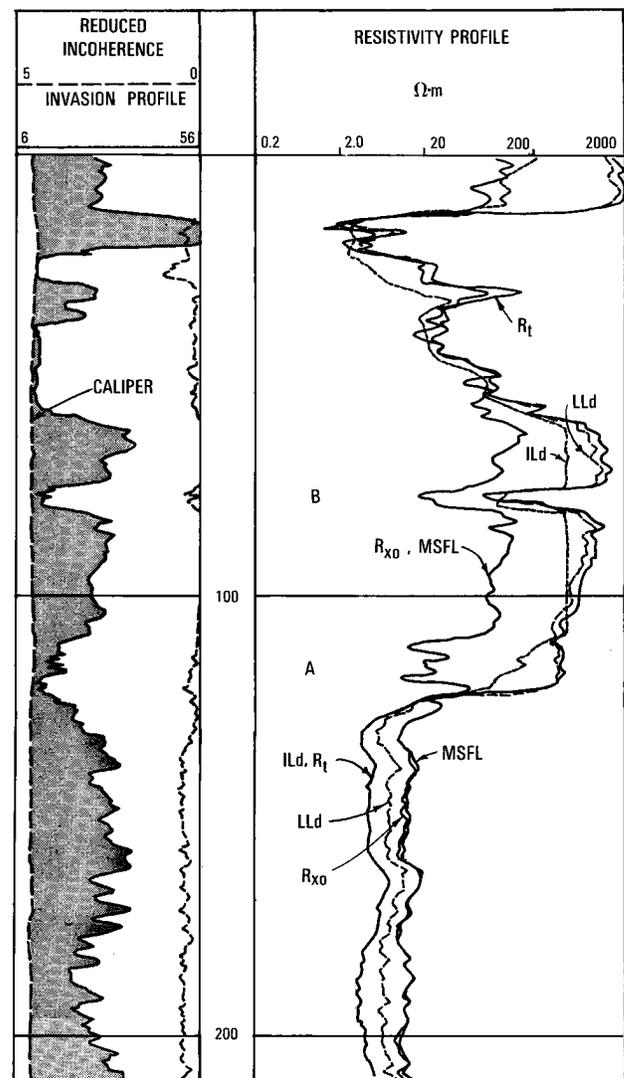


Fig. 7 — Another example of the R_t GLOBAL program. Inputs are resistivity logs — Deep Induction and Laterolog, MSFL*; and outputs are R_t , R_{xo} and diameter of invasion.

Figs. 9, 10 and 11 are the control displays for the input logs. In each display the four curves discussed previously are presented. The shaded areas represent confidence limits for the measurements. As can be seen from the R_{xo} and ρ_b control displays, these limits can be asymmetric.

In this example good agreement can be seen between all logs and their theoretical counterparts indicating that the results are consistent with the interpretation model. This is reflected in the reduced incoherence which is nearly everywhere less than one. This condition is not satisfied, however, in zones A and B, indicating that we should look more closely at the solution in these areas. The problem arises because the LDT, EPT* (Fig. 11) and the R_{xo} output from RTGLOB (Fig. 9) with their excellent vertical resolutions see fine laminations in the two zones. The other measure-

*Mark of Schlumberger.

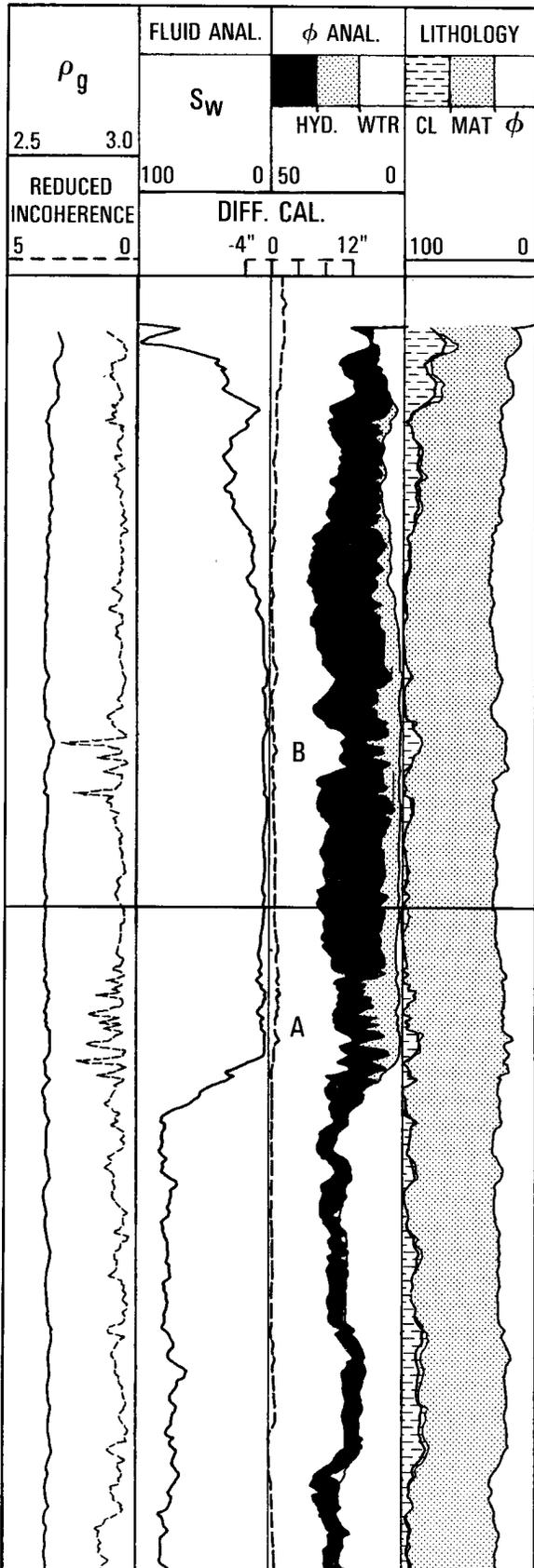


Fig. 8 — Standard presentation of the results from a GLOBAL RIG program. In most respects, this is identical to the traditional presentation. The added "Reduced Incoherence" curve indicates the success of the model fit and minimization process.

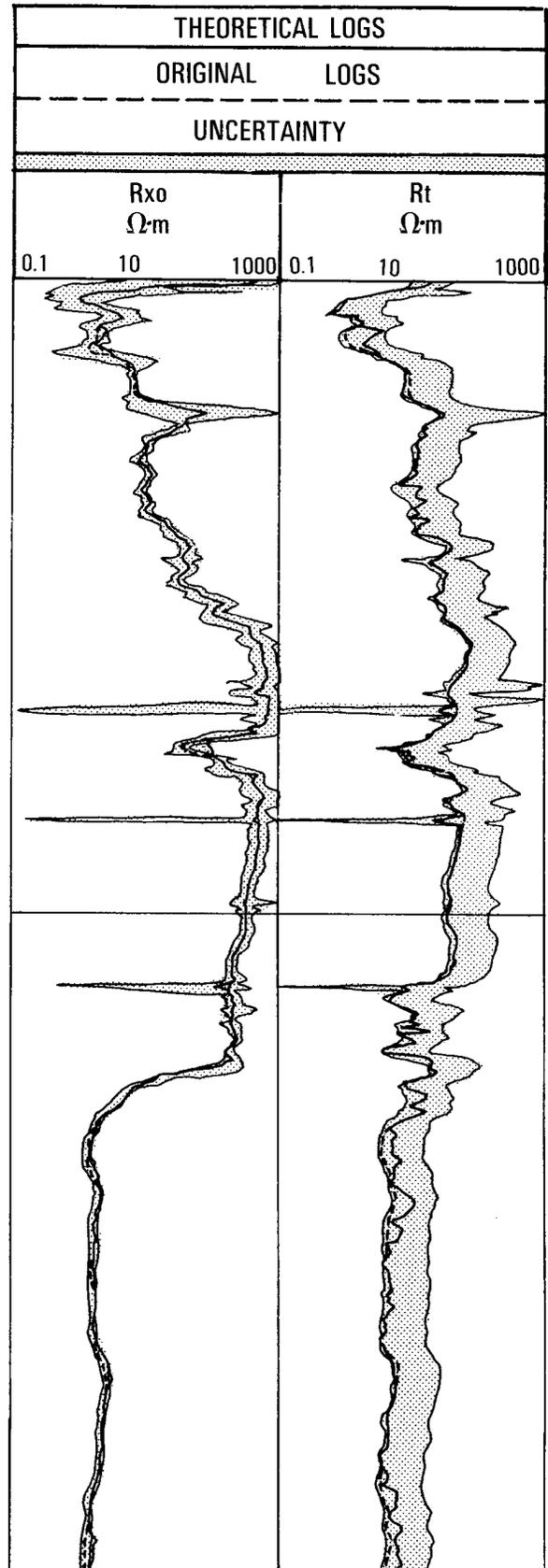


Fig. 9 — Control displays for R_{xo} and R_t , which are outputs from the GLOBAL R_t program and inputs to the GLOBAL interpretation phase (RIG).

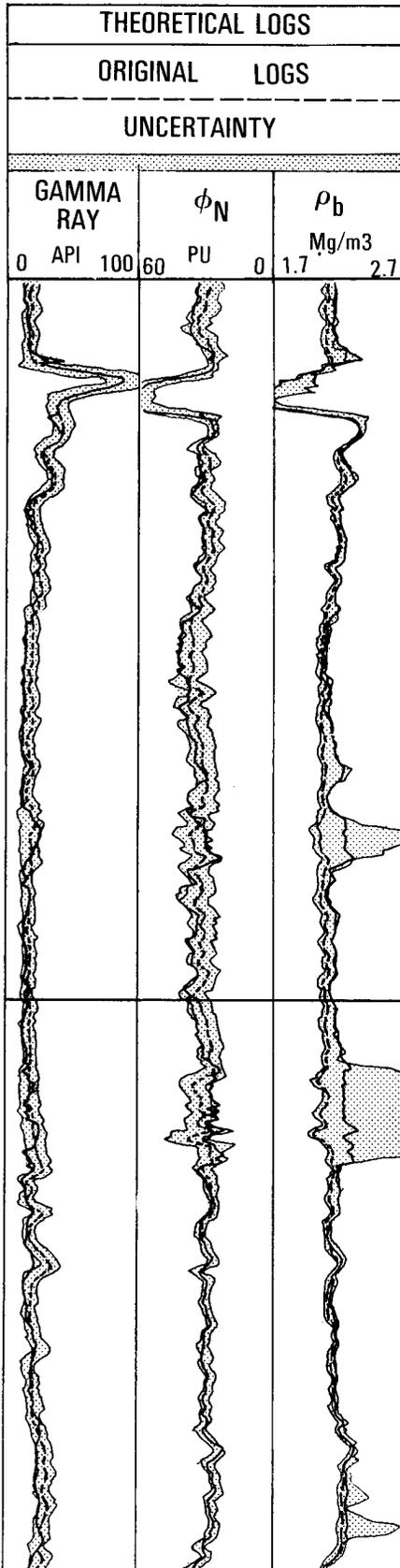


Fig. 10 — Control displays for Gamma Ray, Density and Neutron logs, after RIG processing.

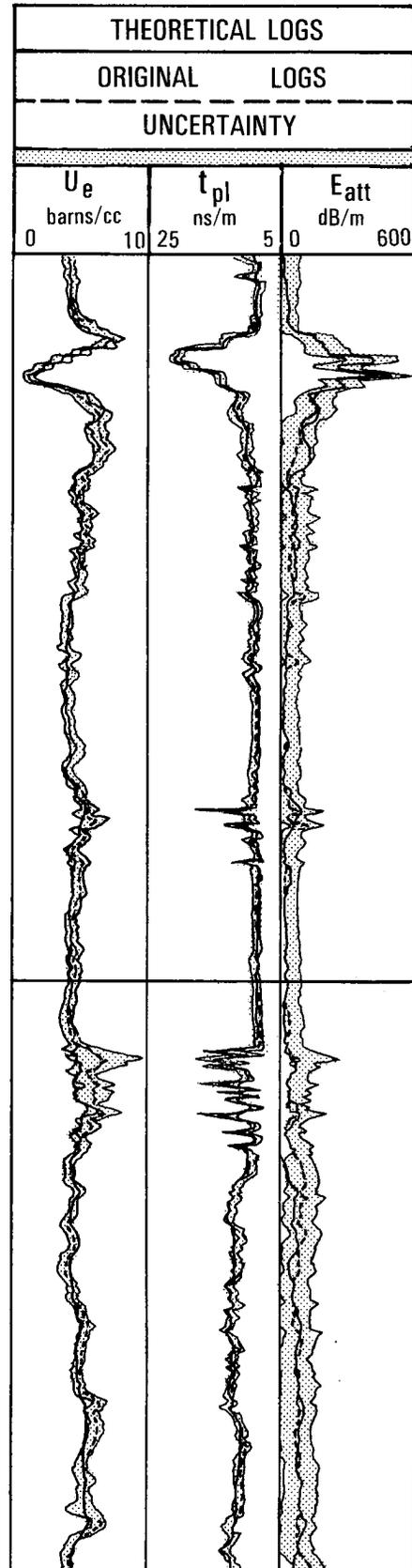


Fig. 11 — Control displays for Lithodensity and Electromagnetic Propagation tools. With GLOBAL's flexibility, these new tools were easily incorporated into the interpretation presented in Fig. 8.

ments do not have the same vertical definition and indicate a porous formation. GLOBAL makes a good compromise indicating the presence of clay and thin laminations. The constancy of the residual water volume bear out this interpretation.

ADVANTAGES OF THE GLOBAL METHOD

The main advantage of the GLOBAL approach is that, by making full use of all available measurements, it leads to more reliable results than conventional programs. Its ability to deal with different models and tools allows a far more flexible approach, particularly in the more difficult interpretation problems.

Other advantages, though less immediately obvious, are important when we consider the problem of interpretation in its human and economic context. These concern the better control of processing and results, and the potential evolution of the GLOBAL CPI chain with advances in geology, geophysics and sensor design.

Let us review briefly these three categories of advantages.

RELIABILITY

Better Behavior in Bad Holes

Due to the smooth operation of the confidence factors, the tools least affected by bad hole are used optimally in bad hole zones; no useful information is lost.

Use of all available tools

The GLOBAL structure permits easy processing of all available logs, without sacrificing the information given by any of them. It makes a synthesis rather than a choice. The most recent Schlumberger sensors have been introduced into GLOBAL, including the Natural Gamma Ray Spectrometry log, the Litho-Density log and the Electromagnetic Propagation log. Standard sensors not conventionally used in open-hole formation evaluation have also been incorporated, e.g. the Thermal Decay Time log.

Use of the Most Adapted Model

The option of varying up to six minerals at a time combined with the use of more numerous tools, allows us to

process very complex or special lithologies, encountered more and more frequently in the search for oil and gas.

The flexibility of the approach permits the selection of the model which is best adapted to the type of formation analyzed. Local knowledge can be naturally introduced by way of local constraints.

QUALITY CONTROL

The proper use of the incoherence and control displays, comparing real and theoretical logs, gives a better understanding of the problems met during the interpretation process. This helps the log analyst replace or modify the model used until a consistent interpretation is made. At the end of the process, the log analyst has not only a set of results, but all the quality control information allowing him to estimate the confidence he can put on the results.

POTENTIAL OF EVOLUTION

The key to the potential evolution of GLOBAL is the use of tool response equations as the central part of the model. These equations are the most natural way to express the knowledge of the functioning of a wireline tool, derived as they are from the physical principles of the tool, and further adjusted by laboratory and core studies.

CONCLUSIONS

The GLOBAL method is a general framework for log interpretation. A variety of tools and formation models can be used at the log analyst's discretion. The method makes the best use of these selections, by computing a maximum likelihood solution.

Its flexibility enables it to easily grow with the introduction of new tools and increasing complexity of models. Provided that the logging suite has sufficient resolution, and individual tool responses are known, GLOBAL should be able to process satisfactorily all types of formations. As of now, the GLOBAL chain delivers results comparable to those of CORIBAND or SARABAND in standard cases, and shows improvement over them in many complex lithology or bad hole examples. In the future, the concept of GLOBAL will be extended to new tools, new models and automatic parameter selection.

NOMENCLATURE

a_i	Log reading of the i^{th} logging measurement	V_{cl}	Volume fraction of clay
a_i^*	Theoretical log reading of the i^{th} logging measurement	V_{ma1}	Volume fraction of mineral; V_{ma2} etc. defined similarly
\underline{a}	N-dimensional array of log readings	SP	Spontaneous potential
C	Conductivity	τ	Sonic interval transit time
d_i	Diameter of invasion	u_i	Standard deviation of total error in i^{th} logging measurement
f_i	i^{th} tool response function	\underline{x}	Multidimensional array of interpretation unknowns
g_j	j^{th} constraint	$\Delta(\underline{a}, \underline{x})$	Incoherence function
GR	Gamma Ray log	ϵ_i	Residual in i^{th} tool response equation
$G(R_t, R_{xo}, d_i)$	Radial geometrical factor function for Induction	ρ_b	Density of formation
$J(R_t, R_{xo}, d_i)$	Radial pseudo geometrical factor function for Laterolog	ρ_{cl}	Density of clay
R_{ILd}	Resistivity from deep Induction	ρ_h	Density of hydrocarbon
R_{LLd}	Resistivity from deep Laterolog	ρ_{ma}	Density of matrix
R_{LLs}	Resistivity from shallow Laterolog	ρ_{mf}	Density of mud filtrate
R_{MSFL}	Resistivity from MSFL*	σ_i	Standard deviation error on i^{th} logging measurement
R_{mf}	Resistivity of mud filtrate	σ_i^-	Assymmetric negative error on i^{th} logging measurement
R_t	Resistivity of virgin formation	σ_i^+	Assymmetric positive error on i^{th} logging measurement
R_w	Resistivity of connate water	σ_k	Standard deviation error on a logging measurement due to one factor (see text)
R_{xo}	Resistivity of invaded zone	τ_i	Standard deviation of error in a tool response equation or constraint
S_{xo}	Water saturation in invaded zone	ϕ	Porosity
S_{xoT}	"Total" porosity water saturation in invaded zone	ϕ_{max}	Porosity maximum limit
S_w	Water saturation in virgin formation	ϕ_n	Porosity from Neutron log
S_{wb}	Bound water fraction of total porosity		
S_{wT}	"Total" porosity water saturation in virgin formation		

*Mark of Schlumberger.

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