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EFFECTIVE INTEGRATION OF CORE AND LOG DATA

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ABSTRACT

The primary purpose of core-to-log data integration is to reduce the uncertainty associated with formation evaluation. In so doing, we take advantage of both the higher precision of core data and the larger scale of investigation of log data. It is particularly important that when tying logs back to core, the calibration algorithm is as well defined as possible.

This paper examines ways of optimising the calibration process. A basic requirement is the definition of a common reference depth scale. A second requirement is to reconcile the different vertical resolutions by the depth-averaging of core data, the signal-enhancement of log data, or both. Essential to this process is the adoption of "key intervals" as control zones for data integration. These procedures can result in a reduced uncertainty which transmits through to reservoir appraisal.

Important new developments will facilitate the integration of core and log data where core recovery is incomplete. These include the ultrasonic monitoring of core entry into the core barrel, the multi-sensor scanning of whole core, and the interactive display of both core and log data in interrogative work-station mode.

Implementation of the optimal data-integration strategy, and of the new upcoming developments, will require cross-discipline collaboration between those responsible for core acquisition, core analysis and wireline log interpretation. A key factor will be the ability to develop interpretative algorithms for cross-scale application.

INTRODUCTION

An important technical goal is to reduce the uncertainty associated with reservoir appraisal. The attainment of this objective will require a more effective integration of the data that contribute to the reservoir model. A key component of the integration process is the reconciliation of data measured at different scales. A fundamental aspect is the integration of core and log data.

The primary purpose of core-log integration is to control log evaluation using data measured under laboratory conditions. This "tying back to core" usually involves plotting measured core values of a given parameter against log-derived values of the same parameter, after some form of depth merging. The resulting data distribution is then used to generate a regression algorithm which can be applied to log data over uncored intervals. It is reasoned that such an algorithm will compensate for departures in the well logs due to poor tool design, erroneous shop and field calibration, engineering error, and imperfect environmental corrections (Cooke-Yarborough, 1987). Thus we seek to take advantage of both the higher precision of core data and the larger scale of investigation of log data.

This approach presupposes that the core data are representative of the reservoir, in terms of both sampling frequency and sample integrity. This supposition is most appropriate when the formation is clean, consolidated, homogeneous, and vertically and laterally extensive with well defined boundaries, and when the core data are free of environmental, instrumental and operational errors. These conditions are rarely satisfied. Even if the data can be measured accurately and precisely, there have frequently been doubts about the representativeness of core data, especially where lithology is markedly variable (Marchant and White, 1968). A key question concerns the disparity in sample size between core and log data (Enderlin et al., 1991). If this disparity can be reduced, an improved data correlation might be achievable.

This paper examines the mechanism of core-log integration and identifies ways in which uncertainty might be reduced. The aim is an improved data reconciliation for better defined reservoir description. The paper therefore focuses on specific issues of reservoir characterization at the mesoscopic (bedding) scale as discussed more generally by Worthington (1991).

The structure is first to identify prerequisites for effective core-log integration, then to list elements of an idealized data integration strategy, to discuss briefly how this strategy might be impeded by a poor understanding of the physics of scaling, and finally to mention some contemporary developments which would facilitate implementation of the strategy.

PREREQUISITES FOR CORE-LOG INTEGRATION

Matched Depths

Core data are identified by drilled depths, logs by wireline depths. The primary vehicles for depth merging are natural gamma ray measurements. Core plug locations should be identified on core gamma records. The various logging runs should be depth-matched to a common wireline depth scale. Thereafter, core and log data should be merged to a common reference depth scale. The determination of a reference depth scale is one of the most difficult tasks facing the data integration specialist. Since the log data are continuous, and can benefit from excellent depth control under favourable conditions (Theys, 1991), a possible approach might be to use a wireline depth scale that has been reconciled with the drillers' depth. This merging procedure might not be feasible where core recovery is incomplete and the natural gamma data are featureless. However, the latter qualification implies a degree of homogeneity that might render the procedure less critical. An alternative procedure has been to match core to electrical images of the wellbore obtained using the formation microscanner (Ekstrom et al., 1987): this has the additional benefit of core orientation. The growing interest in slimhole continuous coring might lead to opportunities for evaluating and comparing these various approaches.

Representative Scales of Measurement

Core plugs should be sufficiently large to provide a meaningful average of the pore structure of each lithological unit or bed that is sampled. The logs should effectively resolve the beds from which core has been taken. The beds are presumed to be laterally consistent in terms of physical properties, at least to the depth of investigation of the logging tools. Where they are not laterally homogeneous, core-log reconciliation will show more pronounced residual departures (Enderlin et al., 1991) and, in extreme cases, core and log data might be poorly correlated (Marchant and White, 1968).

Equivalent Textures

Core data should relate to samples that have been undamaged by the acquisition, handling and cleaning processes. In particular, routine core analysis practice can induce damage where interface-sensitive clay minerals are present (Heaviside et al., Pallatt et al., 1984; 1983; Worthington et al., 1988). Log data should describe zones that have not been damaged by the drilling process; formation damage is, of course, most likely to occur close to the well bore.

Comparable Measurements

The same parameter should be measured both downhole and in the laboratory if the data are to be effectively integrated. For example, electric and induction logs measure horizontal resistivity at given frequencies; it is important that the corresponding laboratory measurements on horizontal core plugs are recorded at similar frequencies to avoid problems arising from the frequency-dependence of electrical data. Furthermore, the correlated data should be reported in the same parametric system. In the case of porosity, one might use total interconnected porosity or free-fluid porosity, but not one of each.

ELEMENTS OF AN IDEALIZED DATA INTEGRATION STRATEGY

Key Intervals

Of the various prerequisites described above, the ones over which we have no control are the relative bed thickness and lateral homogeneity. We have a choice of core plug sizes and can select logging tools to sense different volumes around the near-wellbore zone, but we cannot alter the vertical resolution of logging tools without departing from the standard logging suite. Even then, it may not be possible to measure the same parameter(s) with a sharper resolution, simply because of tool availability. An available option is to restrict the core-log integration to the central parts of relatively thick beds in the first instance. This would allow a "calibration" of the log data to be effected to the exclusion of wireline data close to bed boundaries. The calibration should be restricted to selected key intervals.

A key interval is one which comprises beds whose thicknesses are significantly greater than the coarsest vertical resolution within the logging suite and which has been fully cored. Algorithms for tying logs back to core should be established only for key intervals. No other data should be considered. The criteria for selecting key intervals can be based on Table 1. There, the *tool intrinsic resolution* is an engineering design characteristic (e.g. source-detector spacing), *log sensitivity* is the minimum bed thickness for significant manifestation in the logging curve where there are non-extreme contrasts between beds, and *log parametric resolution* is the minimum bed thickness needed for full manifestation in the logging curve, i.e. the log faithfully records the parametric value for the bed in question (Worthington, 1990). Bed thicknesses should be several times greater than the minimum needed for the logging tool to achieve parametric resolution, i.e. to make a measurement that is as close to the truth as other environmental factors will allow, subject to perfect tool operation. Obviously some compromise will be needed for the induction log in resistive beds, which is justified by, for example, the success of Olson (1986) and Dyos et al. (1988) in reconciling core-derived water saturations with those determined from deep induction logs.

Data Characteristics

Table 2 compares the characteristics of core and log data and indicates which are superior in terms of continuity of sampling, sample volume, accuracy and precision, measurement conditions, and evaluation philosophy. Ideally, we should try to merge the data to derive maximum benefit from the collated database. Thus, we take advantage of the greater accuracy and precision of core data, and the fact that these data can be interpreted directly whereas log data cannot. On the other hand, by merging the data, we link these benefits to the continuous nature and larger sampling volume of log data, and to the advantage that log data relate to in situ conditions. We shall now consider the integration of core and log data in terms of each of these data characteristics.

Evaluation Procedure

Logs are records of physico-chemical characteristics which can be measured downhole: they are not records of the reservoir properties we require to know. The data may need to be corrected for shale or light-hydrocarbon effects. An algorithm is then used to link the corrected physical measurements to porosity, water saturation or possibly permeability, all in appropriate parametric units. The algorithm can be conceptual, empirical or theoretical. It can also be universal, reservoir-specific, or even variable within a reservoir. The form of the algorithm must be clearly established and verified through core control. This is the first level of core calibration of log data.

As an example, let us consider the case of a quartz sand from a North Sea field with isolated micropores within the grains. Bulk density is 2.3 g cm^{-3}. The mineral density is 2.65 g cm^{-3} but the grain density is only 2.55 g cm^{-3}. The conceptual relationship linking porosity ϕ_D to bulk density ρ_b is, for the particular case of the density log,

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (1)$$

where ρ_{ma}, ρ_f are the matrix and fluid densities, respectively. The question is "Which matrix density do we use?" If we follow standard practice and use 2.65 g cm^{-3}, ϕ_D is calculated as an absolute porosity of 21 per cent. This figure includes the isolated micropores and would not correctly indicate the reservoir porosity for practical purposes. But if we are enlightened, we will use the grain density of 2.55 g cm^{-3} for which ϕ_D is calculated as a total interconnected porosity of 16 percent. This figure excludes the isolated micropores which are represented within the correctly measured grain density, the use of which allows good correlation between ϕ_D and porosity determined in the laboratory from helium expansion measurements. Thus algorithm (1) is correctly characterised.

This example emphasises the need to determine precisely those characterising parameters, such as ρ_f and ρ_{ma}, which govern the form of the (conceptual) algorithms relating log measurements to reservoir properties. Another example, this time of an empirical core-calibrated algorithm for permeability prediction from nuclear magnetism and density logs in Western Canada, is that of Logan (1989).

Measurement Conditions

Core-log integration is more effective where the core data themselves relate to simulated reservoir conditions. Ideally, data should be acquired through pressure coring with rapid preservation, with a compatibility of measurement directions where appropriate, and using simulated reservoir fluids, tectonic stresses and reservoir temperatures. Although this general requirement strictly encompasses pressure and temperature, it is general industry practice to consider only effective overburden stresses. At the very least, a reservoir should be studied to establish the influence of stress upon porosity and permeability. If there is no significant dependence, the problem falls away. But if there is a stress effect, some form of correction to core data is needed before these data can be used to calibrate log data. The specification of experimental conditions is a crucial step in ensuring the accuracy and representativeness of core data.

Accuracy and Precision

It is the practice to assume correctly functioning systems both in the laboratory and in situ. Uncertainties in log data are caused by the remoteness and the environment of tool measurement. Corrections for borehole effects, invasion effects, and bed thickness all have inherent errors. The error associated with the bed-thickness correction is greater than that for borehole correction. To overcome this problem, log readings should be chosen on plateaux where appropriate. Other errors are partly accommodated in tying back to core. Log data can be greatly improved by signal enhancement or deconvolution processing (Dyos, 1986). This is an area which will continue to advance rapidly. In contrast, core data are seen as relatively accurate and precise (Hamilton and Stewart, 1983).

As an example, Fig. 1 illustrates the tying back to core of a density log. This log was run in a shallow cored hole drilled for coal exploration through thin beds with excellent depth control. There was a negligible mud cake and therefore only the long-spaced density data are shown. Fig. 1a contains unprocessed log data which show departures in terms of accuracy (gradient $\neq 1$) and precision (degree of data scatter). The signal-enhanced density log (Fig. 1b) shows a marked increase in both accuracy and precision. In this example, the excellent depth control allows the benefits of signal enhancement to be strongly evident. The agreement would be improved still further if the vertical resolutions of log and core data were compatible.

Continuity and Sampling Volume

These two data characteristics are considered separately. Logs hold the advantage in both cases being continuous and sensing a larger volume. We need to manipulate core data to bring them closer to the logs.

The continuity of core data is limited by the sampling interval chosen for routine core analysis although special core analysis studies have more flexibility. The sampling interval for plugs must no longer be considered in isolation from the logs. Key intervals should be chosen by considering log data in conjunction with core natural gamma records. Identified key intervals should have a plug sampling interval of 6 inches. Plugs should be taken away from bed boundaries. This strategy would provide the same continuity in core data as in conventional log data.

Plug sampling volume can vary from one to ten percent of the volume sensed by logs. The locations of plugs for special core analysis should be guided by X-ray CT scanning where possible to avoid localised heterogeneities which the log would suppress. Plugs should be taken horizontally for resistivity and permeability measurements and vertically for sonic measurements. This would allow directional compatibility with the corresponding well logs or formation tests. The core data should be averaged over a distance that corresponds to the vertical resolution of the appropriate logging tool. If the tool has been subjected to signal enhancement, so that the vertical resolution is processed to be sharper, it is the latter distance over which plug averages should be determined. This procedure will take place over selected key intervals for which plugs have been sampled at six-inch intervals.

The simplest approach would be a five-point running mean which would bring the resolution of the core data closer to that of conventional log data. It can be shown that if the core plugs are from the same bed, this procedure carried out with equal weightings will reduce uncertainty by more than half. The averaging of core data can be designed to reflect the response curve of the corresponding logging tool (Barlai, 1979) by using appropriate weightings. This refinement might increase the physical significance of the resulting mean.

Fig. 2 depicts a simulated density log over a model interval that contains six porous beds, with porosities 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, and with shale strata between them. Each bed is 8 ft thick and each has been sampled at 6-inch intervals starting 3 inches into the bed. Thus, plugged intervals are 0.25, 0.75, 1.25 ..., ft, measured from a bed boundary. The core data are specified to show a cyclicity of bulk density. It is presumed that each core plug samples a horizontal homogeneous layer of thickness six inches. The simulated density log averages the core data, a feature which is clearly evident in Fig. 2.

In a real situation, we would be confronted with the density log and would crossplot this against the core data, as shown in Fig. 3a. The inputs to this figure are the core data measured at the specified levels and digitised log data sampled at those same levels. The net result is a scatter of data about the line of unit gradient with outliers due to shoulder-bed effects.

In contrast, Fig. 3b shows the same plot but with the core data averaged by a five-point running mean over a vertical distance of 2 ft, which is approaching the vertical resolution of the density tool (cf. Table 1). Now the scatter has virtually disappeared. Thus, while it is not possible to account for lateral near-wellbore heterogeneities that the tool might see but the core would not, it is possible to account for heterogeneities vertically with both log and core sampling at different scales and therefore with different resolutions.

This approach will be less effective in heterogeneous and/or thinly bedded formations: for such cases a strip-sampling approach has been proposed (Dahlberg and Fitz, 1988). This involves the strip-sampling of core over a distance that approximates the spatial resolution of the logging tool. This technique involves destructive testing. It allows the sample to be mixed over the length of the strip. However, it is not standard practice.

CORE-DERIVED ALGORITHMS FOR LOG INTERPRETATION

There have been numerous examples in the literature of core data being compared with the interpretations of log data. These examples draw upon the strategic elements of the previous section to widely varying degrees. Invariably, the form of the interpretative algorithm is determined at the core scale and then applied at the log scale. Although this approach has often worked well, there have been occasions where data reconciliation has not been possible, even where the formation seems laterally homogeneous. These mis-matches have been responsible for the view that core and log data might have a residual incompatibility which cannot be reconciled even under favourable conditions. In the case of core validation of log interpretation, a possible contributive explanation might be the sensitivity to upscaling of the empirical algorithms used in petrophysics.

To illustrate this argument, let us consider a unit block of porous material that is divided into halves, each of which is homogeneous and isotropic (Fig. 4). The two halves are characterised by porosities and formation resistivity factors ϕ_1, F_1 and ϕ_2, F_2. We want to relate F_1 and F_2 to the formation factor F of a unit block that is homogeneous and is electrically equivalent to the divided block. In logging terms, we might imagine the characteristics of the uniform block to be the interpretation of logs that cannot resolve separately the two halves, which would be characterised by core analysis. The problem therefore simulates the relationship of core data to log data.

There are two ways in which we can establish the relationship between F_1 and F_2, on the one hand, and F, on the other. One approach is to use the concept of resistors in parallel to calculate F directly: this approach is permissible because the formation factors are scaled resistivities. We find that:

$$\frac{1}{2}\left(\frac{1}{F_1} + \frac{1}{F_2}\right) = \frac{1}{F} \qquad (2)$$

The second approach is to use the well-established averaging algorithm for porosity and to substitute formation factors for porosities using Archie's first law (Archie, 1942). In this case, the starting point is the expression:

$$\frac{1}{2}\left(\phi_1 + \phi_2\right) = \phi \qquad (3)$$

If we presume the following form of Archie's first law

$$F = \frac{1}{\phi^m} \qquad (4)$$

where m is an empirical exponent that is related to pore geometry and is assumed constant (default value = 2), we can substitute for ϕ_1, ϕ_2 and ϕ in equation (3) as follows:

$$\frac{1}{2}\left\{\left(\frac{1}{F_1}\right)^{1/m} + \left(\frac{1}{F_2}\right)^{1/m}\right\} = \left(\frac{1}{F}\right)^{1/m} \qquad (5)$$

It can be seen that equations (2) and (5) are identical only if m = 1. This condition is known to be satisfied only for systems of parallel capillaries, which have not been introduced here. Otherwise, equations (2) and (5) provide different estimates of F. Thus, in the general case, our system of equations is not robust in terms of cross-scale application, i.e. different estimates of F are obtained by taking routes 1 and 2 (Fig. 4). Possible explanations are that the parallel resistor concept cannot be applied to resistors that are in electrical contact or, perhaps more likely, that the empirical origin of Archie's law makes the exponent m a function of the scale of measurement.

As a second illustration, let us consider another divided unit block (Fig. 5), the two halves being characterised by porosities and densities ϕ_1, ρ_1 and ϕ_2, ρ_2. We want to relate ρ_1 and ρ_2 to the density ρ_b of a homogeneous unit block that is materially equivalent to the divided block. Again, there are two ways in which this task might be addressed. The first approach is based on a summation of masses so that:

$$\frac{1}{2}\left(\rho_1 + \rho_2\right) = \rho_b \qquad (6)$$

The second approach is to use equation (3) in conjunction with the density mixing-law for porous media, i.e.

$$\rho_b = \phi \; \rho_f + (1 - \phi) \; \rho_{ma} \qquad (7)$$

where ρ_f, ρ_{ma} are, again, the densities of the interstitial fluid and the rock matrix, respectively. Equation (7) can be written:

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (8)$$

Equation (8) has the same form as equation (1). We can use equation (8) to substitute for ϕ in equation (3) so that:

$$\frac{1}{2}\left(\frac{\rho_{ma} - \rho_1}{\rho_{ma} - \rho_f}\right) + \frac{1}{2}\left(\frac{\rho_{ma} - \rho_2}{\rho_{ma} - \rho_f}\right) = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (9)$$

Equation (9) reduces to equation (6). This means that both approaches lead to the same prediction of ρ_b. Thus, the system of equations is robust in terms of cross-scale application, i.e. the same estimates of ρ_b are obtained by taking routes 1 and 2 (Fig. 5). It is important to note that these equations are conceptual, in contrast to the previous example where the system was partly founded on empiricism.

As petrophysics continues to move strongly towards cross-discipline integration in pursuit of improved reservoir description, the question of the scale-compatibility of petrophysical algorithms will be subject to further scrutiny. Even if core analysis practised in accordance with a sound technical strategy does not prove to be fully reconcilable with log data, it does provide some ground-truthing which, if properly used, can aid in the quantification of uncertainty and the management of risk. Further progress will no doubt be forthcoming from the technical advances that are in hand.

CONTEMPORARY DEVELOPMENTS

The strongest technical drive to integrate core and log data at the present time is to be found in the technology and engineering development function of the Ocean Drilling Program (ODP). The ODP was initiated in 1983 and it has, to date, been responsible for some 40 scientific expeditions (legs) to explore the structure and history of the Earth as revealed beneath the oceans. The exploration strategy has been to drill fully-cored boreholes at target sites and then to run a full suite of wireline logs at each site. The database of core and log data is therefore voluminous and, if not managed effectively, it might become difficult to handle, even during the course of a single leg. The present objective is to provide an integrated database of core and log data for each drilled site in as close to real time as possible. The following ongoing technical developments are directed at achieving this goal.

Sonic Core Monitor

In cases of incomplete core recovery it has been the practice to "hang" the recovered core from the top of the core barrel as though recovery had been continuous over the uppermost portion of the interval and zero over the rest. The sonic core monitor is designed to record the rate of core recovery so that, by comparing this rate with the rate of bit penetration, the correct location of each core piece within the core barrel can be determined.

The system comprises an ultrasonic source/sensor at the top of the core barrel and a reflector positioned on the top of the advancing core (Fig. 6). The length of the core column is continuously recorded by measuring the travel time of the reflected pulse. An example of data output is shown in Fig. 7. The zones of poor core recovery are immediately recognisable. Now that the concept is proven, the prototype design is being upgraded through the development of a second tool for routine field use in consolidated rocks.

Multi-Sensor Track

The oil industry traditionally records core natural gamma counts by running the recovered core on a belt through a gamma-ray detector. The ODP has extended this concept to include other continuous measurements such as magnetic susceptibility, gamma-ray attenuation and P-wave velocity. This so-called "multi-sensor track" is a screening facility: it provides a reference scale to which other core data can be related, e.g. physical properties measurements on core plugs.

Interactive Data Display

The aim is to integrate laboratory data and downhole measurements within a common user-friendly system. The system is required to be interrogatable and it must have the capability to select and display in interactive mode all those data that are relevant to a particular interpretation process. There are four essential stages in this process:

(i) Integrate core data

(ii) Integrate log data

(iii) Merge core and log data

(iv) Display core and log data

At the present time item (i) is receiving the highest priority. Data are being stored as computerized barrel sheets for which the display can be varied. An example is shown in Fig. 8. The intention is to merge the log data so that they, too, can be displayed on call in the available right-hand tracks. This would mean that any log or core data could be called up and displayed with a common depth scale subject only to track availability. This facility would provide the opportunity for interactive data interpretation using the core-log database actually during the course of an ODP leg.

CONCLUSIONS

Core-log correlation is an integral component of reservoir characterisation practice. It can be enhanced by the judicious selection of key intervals comprising relatively thick, fully cored beds. Key intervals should be targeted on the basis of seismic and geological zonation and the chararcter and quality of log data. Plug selection should be driven by the need for compatibility between the different scales of measurement, principally the core and log scales. Plug locations should be chosen on the basis of log responses and X-ray CT scanning, the latter to investigate any heterogeneities in selected core pieces. For maximum effectiveness the plugs should be selected by the petrophysicists who are ultimately responsible for log evaluation. This means that geologists and petrophysicists must work as a team, not in isolation.

The clear goal is a significant reduction in uncertainty. The key to reducing uncertainty is to see the drilling, core selection and measurement, and wireline logging as components of a coupled system which must be dovetailed if maximum benefits are to be derived. However, the goal will not be fully achieved unless there is also an integration of those people who are active in these traditionally distinct areas.

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TABLE 1

VERTICAL RESOLUTIONS OF LOGGING TOOLS

LOG	TOOL INTRINSIC RESOLUTION* (m)	LOG SENSITIVITY** (m)	LOG PARAMETRIC RESOLUTION** (m)	
Gamma Ray	0.2-0.3	0.3-0.4	0.6-0.75	
Density	0.4	0.25-0.3	0.45-0.6	
Induction	2.1-2.4	0.75-0.9	1.2-1.5 10	(Conductive Beds) (Resistive Beds)
Neutron	0.4	0.5-0.6	2.4-2.6	
Sonic	0.6	0.6-0.8	1.3-1.4	

* from Allen et al. (1988)
** assumes no environmental effects, no noise

Notes:
TOOL INTRINSIC RESOLUTION is a tool design characteristic:
LOG SENSITIVITY is the minimum bed thickness that can be seen as an event in the logging curve:
LOG PARAMETRIC RESOLUTION is the minimum bed thickness needed for full manifestation of the logged parameter(s) in the logging curve.

TABLE 2

RELATIVE MERITS OF CORE AND LOG DATA

CHARACTERISTIC	CORE		LOG
Evaluation Procedure	Direct	←	Indirect
Measurement Conditions	Experimental	→	In situ
Accuracy and Precision	Higher	←	Lower
Continuity	Discontinuous	→	Continuous
Sampling Volume	Smaller	→	Larger

Arrows indicate the more desirable data

Example of crossplots of core vs log density for
(a) Conventional log data and (b) Signal-enhanced log data

(courtesy Dyos, C.J., personal communication)

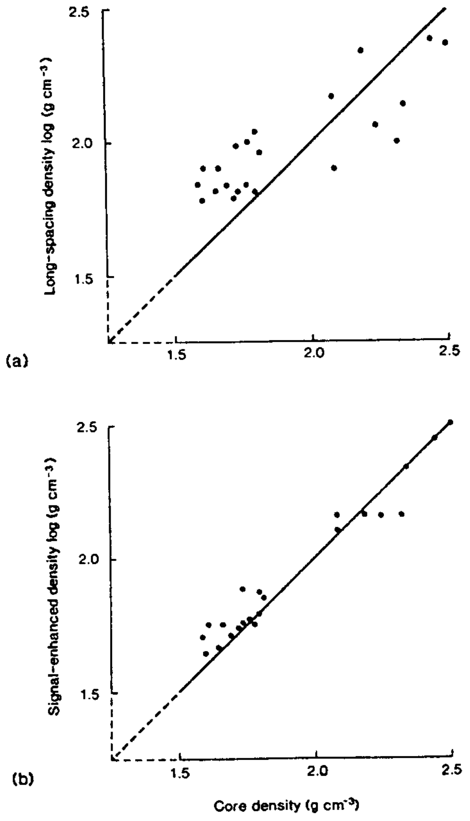


Figure 1

Simulated density log for alternating sand-shale model sequence

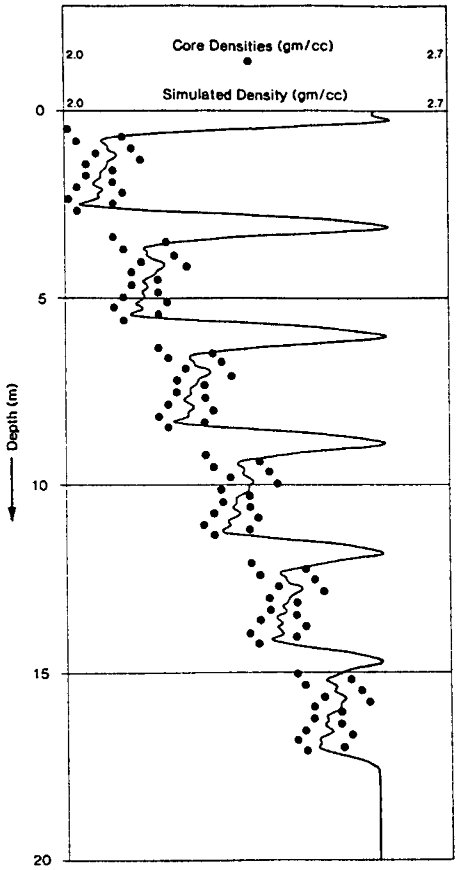


Figure 2

Crossplots of core density vs log density for (a) Level-by-level correlation and (b) Five-point depth-averaging of core data, for model of Figure 2

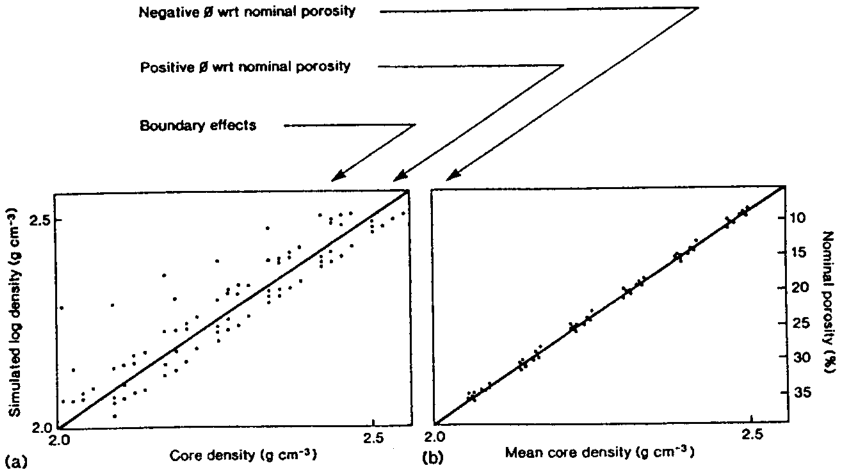


Figure 3

Example of non-robust algorithm for cross-scaling
(Archie equation)

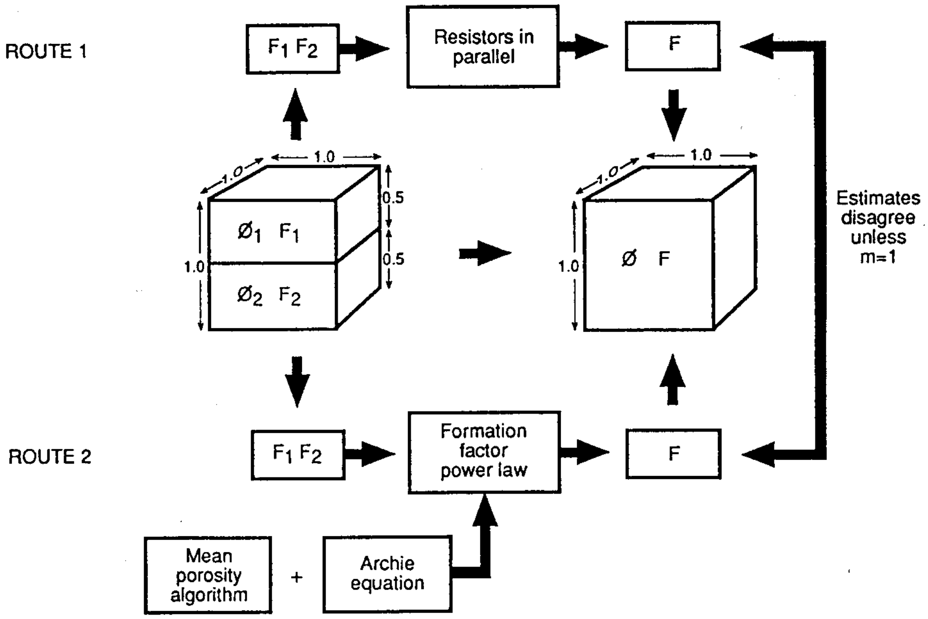


Figure 4

Example of robust algorithm for cross-scaling
(Density - porosity equation)

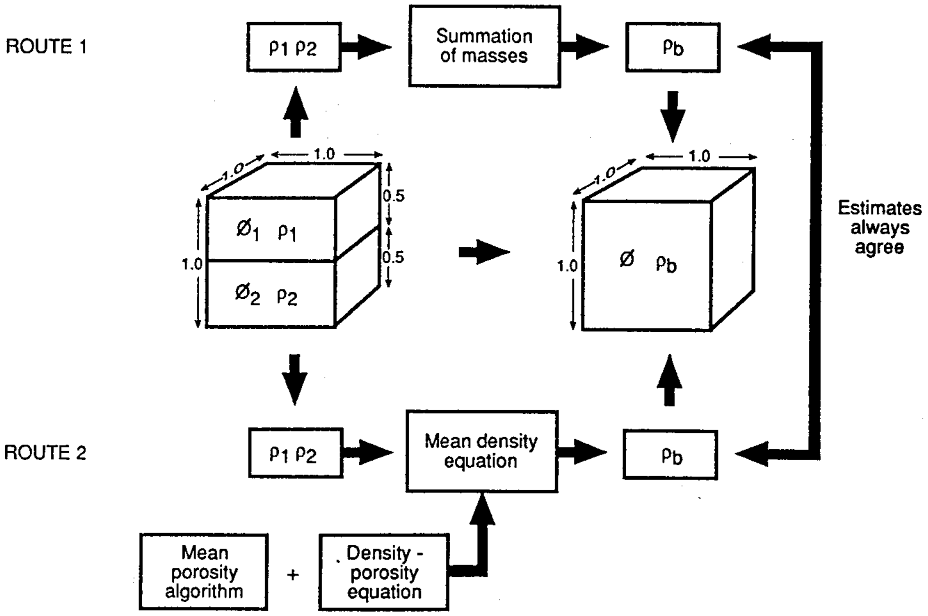


Figure 5

Sonic core monitor (Phase I)

(courtesy Huey.D., personal communication)

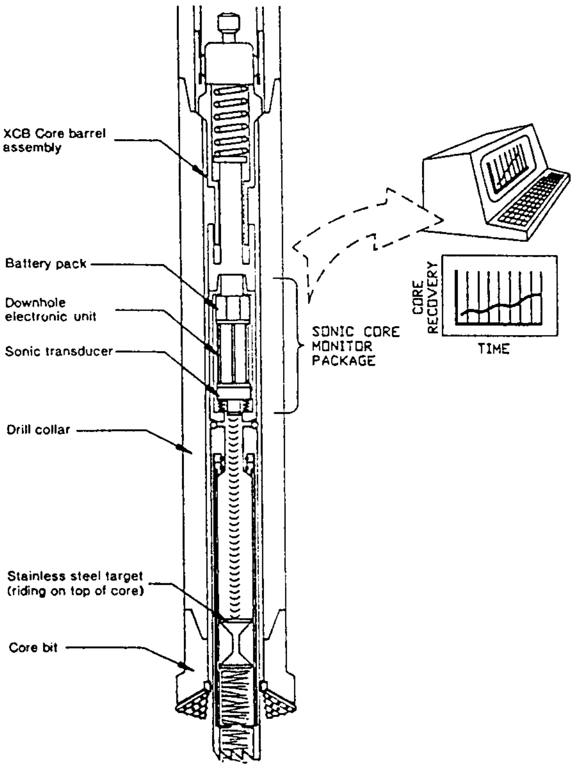


Figure 6

Sonic core monitor
Penetration vs corrected core height

(courtesy Huey D., personal communication)

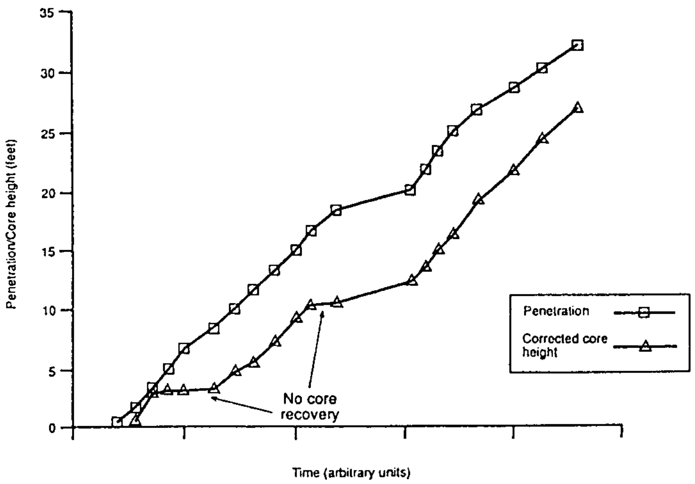
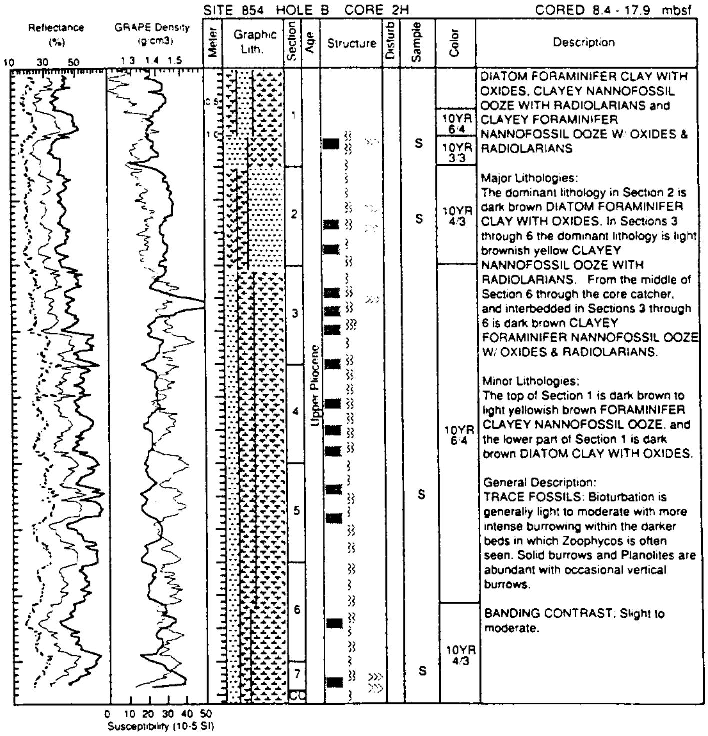


Figure 7

EXAMPLE OF A COMPUTERISED CORE BARREL SHEET

(courtsey Janecek, T., personal communication)



SITE 854 HOLE B CORE 2H

CORED 8.4 - 17.9 mbsf

Description

DIATOM FORAMINIFER CLAY WITH OXIDES, CLAYEY NANNOFOSSIL OOZE WITH RADIOLARIANS and CLAYEY FORAMINIFER NANNOFOSSIL OOZE W/ OXIDES & RADIOLARIANS

Major Lithologies:
The dominant lithology in Section 2 is dark brown DIATOM FORAMINIFER CLAY WITH OXIDES. In Sections 3 through 6 the dominant lithology is light brownish yellow CLAYEY NANNOFOSSIL OOZE WITH RADIOLARIANS. From the middle of Section 6 through the core catcher, and interbedded in Sections 3 through 6 is dark brown CLAYEY FORAMINIFER NANNOFOSSIL OOZE W/ OXIDES & RADIOLARIANS.

Minor Lithologies:
The top of Section 1 is dark brown to light yellowish brown FORAMINIFER CLAYEY NANNOFOSSIL OOZE, and the lower part of Section 1 is dark brown DIATOM CLAY WITH OXIDES.

General Description:
TRACE FOSSILS: Bioturbation is generally light to moderate with more intense burrowing within the darker beds in which Zoophycos is often seen. Solid burrows and Planolites are abundant with occasional vertical burrows.

BANDING CONTRAST: Slight to moderate.

Figure 8