PARES Petroleum and Reservoir Engineering Services

Petroleum Engineering Department

Internal Memorandum

Documentation

of

MGSPC Log Analysis Program

by

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PREFACE

This documentation file is distributed as an Adobe PDF (Portable Document Format) file entitled MGSPC12.PDF, the documentation for the program called MGSPC12.EXE. You will need the Adobe Acrobat Reader Version 2.0 or higher software in order to read and/or print the PDF formatted file.

This documentation and program will be of value to the Development Petroleum Engineering, Formation Evaluation Department as a quantitative analysis tool under the circumstances described. Additionally, this documentation and program will be an invaluable training tool for young engineers venturing into quantitative evaluation. To have the equations and definitions in this documentation presented in one place and in a consistent manner will answer many questions and save time searching through numerous publications. Such information is not always written and/or presented in a practical and/or consistent manner in the literature.

For the beginning Petrophysicist, this documentation and program should provided a valuable source of information and tool for making comparative computations. The Petrophysicist will be able to see which parameters and/or log inputs and under what conditions they affect the analysis results, whether significantly or minimally. Having such a program as a basic tool to perform comparative computations will aid in the conceptual thinking involved in more advanced quantitative evaluation such as Petro View Plus and/or ELAN [1] . Also the program can be used in the determination of many of the parameters utilized in the more advanced quantitative evaluations. Such evaluations often start out utilizing a basic lithological model and input parameters which are refined from further and detailed core data study and the integration of drill stem test results.

The log inputs, parameters and definitions presented herein represent those that are considered fundamental to quantitative petrophysical reservoir evaluation, i.e. a minimum data set and input parameters. The Petrophysicist performing such evaluations has the arduous task of deciding how to apply a variety of tools and models to obtain the most accurate results obtainable, i.e. results where the ever present uncertainty is minimized.

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[1] Trademarks of Schlumberger, ELAN, is an abbreviation for Elemental Analysis - a probabilistic well log analysis program, Petro View Plus is a simplified and deterministic application of ELAN. MGSPC12 is a deterministic program.

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PROGRAM NAME - VERSION

MGSPC - Version 1.2

INTRODUCTION

On many occasions well log data is not readily available in digital form but as displays in the form of optical prints. None the less, it remains necessary for the petrophysicist to make a determination of fundamental petrophysical reservoir properties such as lithology, water saturation, porosity, hydrocarbon type, net pay etc. These evaluations are often required to be made from a facsimile of logs from an operating rig, paper copies obtained during data acquisition, prints received from partners, old well files and/or other sources. The program MGSPC was written to facilitate petrophysical evaluation under these circumstances with the purpose of providing comparable quantitative results as would be obtained by applying analytical procedures performed on a UNIX Workstation or other similar system.

This documentation is prepared for those who have a fundamental proficiency in log analysis, petrophysics and basic computing. It is the responsibility and judgment of the user as to the accuracy and quality of any results obtained by using MGSPC or any other program. Every effort has been made to insure that the numerical results are accurate, however accuracy also depends upon the quality of all of the various input logs and parameters.

The MGSPC program was not created to be a “cure all” or a substitute for advanced petrophysical analysis of digitally recorded data, but to save valuable time sorting through log interpretation chart books, doing manual computations with a hand held calculator, using spreadsheets with limited equations and logic. Even with the use of spreadsheets, it is difficult to make all of the environmental corrections of the Neutron log for example. Environmental corrections are incorporated in MGSPC and represent one significant advantage over the methods previously mentioned.

Another practical utilization of MGSPC is in sensitivity analysis. Since there are many interrelated quantities used to derive formation porosity and water saturation, it can be difficult to gauge the change in output results with respect to a change in an input log or parameter. Or, how does the uncertainty in one or more input parameters or logs affect the uncertainty of the results? Once an acceptable result is obtained then it is an easy task to vary one or more parameters or log inputs to see the effect on the output results.

FORTRAN PROGRAM

MGSPC is written in FORTRAN and should function on any x286 or above computer. The algorithms used have been thoroughly researched in the literature and tested in various petroleum reservoir environments.

The inputs and outputs are ASCII files which can be annotated, printed and/or imported into spreadsheets and/or word processors for presentation purposes. Once an ASCII table of log data is established, it is a simple matter to change one or more parameters and recalculate the results. These results should be quantitatively comparable to conventional log analysis performed on larger computer systems. **Appendix One** shows the FORTRAN format statements used to write out the ASCII input/output files each of which is described herein.

The program requires that the user input data that represents a real physical environment. No limits have been place on the numerical values of the input data. For example, a temperature gradient may be 1.20 DegF/100Ft. and must have as its input value 1.20 not -12.0, i.e. a typographical error. *Entering a completely unphysical number for any input log or parameter will either cause the program to abort or yield totally unreasonable results*.

The formats of the input and output files are fixed. This does not present a problem since all input files can be generated by the program itself as output files during program execution.

PROCEDURE

There are primarily two approaches to applying the MGSPC program. One approach is when both the parameters and the log data are entered and computations made concurrently. The second approach is when both parameters and log data have been input into an ASCII file and computations are to be made accordingly. With either approach, it is possible to make one or more parameter changes in the input parameters file and re-compute the results. Both approaches require an input Parameters File which can be created by an initial run of the program or edited manually.

Note that the inputs, except for depth, are in English rather than Metric units. Since the program uses the temperature gradient and mean surface temperature to vary formation temperature as a function of depth, it is of paramount importance that the answer to the question/prompt “Is DEPTH Input In Meters? (Y or N)” be answered correctly.

INPUT FILES

Two input files are read by the program, both of which can be generated by an initial run of MGSPC. The file names are at the user's discretion. The first file, referred to as the **Parameters File**, contains the value of Rw @ 75DegF, for example, and other constant values. The description of this ASCII file's parameters is as follows:

Mnemonic	Description	Units
TGRD	Temperature Gradient	DegF/100Ft
MST	Mean Surface Temperature	DegF
BTSZ	Bit Size	in
WMUD	Mud Weight	lb/gal
RHOM	Matrix Density	gm/cc
DTM	Sonic Matrix Travel Time	us/ft
GRMA	Gamma Ray response Clean Formation	API
GRSH	Gamma Ray response 100% Shale	API
RW75	Formation Water Resistivity @ 75DegF	Ohm-M
RMF75	Mud Filtrate Resistivity @ 75DegF	Ohm-M
RMC75	Mud Cake Resistivity @ 75DegF	Ohm-M
RM75	Mud Resistivity @ 75DegF	Ohm-M
NLSH	Neutron response 100% Shale LS Units	v/v
RHSH	Density response 100% Shale	gm/cc
DTSH	Sonic response 100% Shale	us/ft
RTSH	True resistivity of 100% Shale	Ohm-M
RXSH	Flushed zone resistivity 100% Shale	Ohm-M
SWEQ	Water Saturation Equation Switch	
GREQ	Gamma Ray Equation Switch	
A	Formation Factor Coefficient	F=A/Φ**M
M	Cementation Exponent	F=A/Φ**M
N	Saturation Exponent; for the Archie Equation, N=2 implies	Sw^2=F*Rw/Rt
CEC	Cationic Exchange Capacity	meq/gm
XDIP	Dip Angle	degrees

The order in which these constants appear in the input file does not matter since the MGSPC program uses a sort routine to re-order them before using them for computational purposes. However, when the program writes out the Parameters File, it uses a fixed format and sequence. Remember that the format of the Parameters File is fixed, i.e. the mnemonic followed by its value. If the Parameter File has not been created then the user is prompted for the following Parameter File inputs similarly as shown:

	(DegF/100Ft)	(DegF)	(in)	(lb/gal)		
INPUT:	TGRD	MST	BTSZ	WMUD		:
	(gm/cc)	(us/ft)	(API)	(API)		
INPUT:	RHOM	DTM	GRMA	GRSH		:
	(ohm-m)	(ohm-m)	(ohm-m)	(ohm-m)		
INPUT:	RW75	RMF75	RMC75	RM75		:
	(v/v)	(gm/cc)	(us/ft)	(ohm-m)	(ohm-m)	
INPUT:	NLSH	RHSH	DTSH	RTSH	RXSH	:
	-	-	-	1-13	1-7	
INPUT:	A	M	N	SWEQ	GREQ	:

After these inputs are written out to the Parameters File, it is possible to change them during program execution. If a 0 (zero) entry is made for any of these inputs; then the previous value is retained (provided one has been entered previously), which is also shown as part of the prompt. This allows for less typing when changing one parameter value but leaving the rest unchanged.

Entering a -1 (minus one) for either of these parameter inputs is regarded as the "absent value", i.e. the associated log measurement for which that parameter applies is not available for input. However, entering a -1 value for the parameters not associated with a specific log measurement, N, for example, is not advisable except where otherwise indicated. Entering a -1 for TGRD will prompt the user for inputs to compute this parameter. Entering a -1 for RW75 will prompt the user to derive R_w from the Spontaneous Potential log measurement, RMF75 and RM75.

The second file is referred to as the **Data File** and is an ASCII file which contains the log data values. The description of this file is as follows:

Mnemonic	Description	Units
DPTH	Formation Depth	Ft or M
RT	True Formation Resistivity	Ohm-M
RXO	Flushed Zone Resistivity	Ohm-M
RHOB	Formation Density Log Response	gm/cc
CNLS	Compensated Neutron Log Response LS units	v/v
DLT	Sonic Log Response	us/ft
GR	Gamma Ray Log Response	API
CLP	Caliper, Hole Size	in
CLIM	Caliper limit at which DLT is used for Φ computation	in

The Data File contains the input log values which are limited to conventional measurements. The CLIM value has been retained in the Data file as opposed to the Parameters File to allow for variation in the conditions under which porosity is derived from the Sonic log only.

The user is prompted for the following Data File inputs similarly as shown:

```
INPUT: DPTH (Ft. or M)                                    :
INPUT: CLP(in),          RT (Ohm-m),      RXO (Ohm-m)     :
INPUT: RHOB(gm/cc),      CNLS(v/v),       GR(API)         :
INPUT: DLT(us/ft),       CLIM(in)                         :
```

and entries made accordingly. If a 0 (zero) entry is made for any of these inputs except for DPTH, then the previous value is retained (provided one has already been entered or read), which is also shown as part of the prompt. This allows for less typing when a given log does not change from one depth interval to the next. Entering -1 (minus one) for either of the log input values is regarded as the "absent value", i.e. no log data for that measurement is available. Minimum log data input is DPTH, RT, GR and one porosity log.

OUTPUT FILES

There are two output files. One is a file named by the program as **MGSPC12.DAT** and the other is referred to as the log **Analysis File**. The Analysis File contains some of the input logs, primarily for reference and relevant computed results, e.g. porosity and water saturation among others. The description of the log analysis ASCII output file is as follows:

Mnemonic	Description	Units
DPTH	Formation Depth	Ft or M
RT	True Formation Resistivity	Ohm-M
RXO	Flushed Zone Resistivity	Ohm-M
RHOB	Formation Density Log Response	gm/cc
CNLS	Compensated Neutron Log Response LS units	v/v
DLT	Sonic Log Response	us/ft
GR	Gamma Ray Log Response	API
VSH	Volume of Shale	v/v
ROHY	In-situ Hydrocarbon Density	gm/cc
SXO	Flushed Zone Water Saturation	v/v
PHIE	Effective Porosity	v/v
SW	Water Saturation Undisturbed Zone	v/v

The first part of the Analysis File is a header section. In addition to the input logs and computed results in the Analysis File, the header section contains some of the parameters from the Parameters File and some of the computed parameters. Whenever one or more of the parameters are changed during program execution, this header section is printed again into the Analysis File to reflect the changes. Saving these changes to a new Parameters File is at the option and discretion of the user. The description of these header section output parameters and their associated units are as follows:

Mnemonic	Description	Units
WMUD	Mud Weight	lb/gal
RTSH	True resistivity of 100% Shale	OhmM
RXSH	Flushed zone resistivity 100% Shale	Ohm-M
A	Formation Factor Coefficient	F=A/Φ**M
M	Cementation Exponent	F=A/Φ**M
N	Saturation Exponent; for the Archie Equation, N=2 implies	Sw^2=F*Rw/Rt
SWEQ	Water Saturation Equation Switch	
GREQ	Gamma Ray Equation Switch	
BCP	Borehole Compaction Factor for Wyllie Time Average Equation	
DTFL	In-Situ (Mud Filtrate) Fluid Travel Time	us/ft
BTSZ	Bit Size	in
DTSH	Sonic response 100% Shale	us/ft
RHOM	Matrix Density	gm/cc
NLSH	Neutron response 100% Shale LS Units	v/v
RHSH	Density response 100% Shale	gm/cc
TGRD	Temperature Gradient	DegF/100Ft
MST	Mean Surface Temperature	DegF
RW75	Formation Water Resistivity @ 75DegF	Ohm-M
RMF75	Mud Filtrate Resistivity @ 75DegF	Ohm-M
RMC75	Mud Cake Resistivity @ 75DegF	Ohm-M
GRMA	Gamma Ray response Clean Formation	API
GRSH	Gamma Ray response 100% Shale	API
RHFL	In-Situ Mud Filtrate Density	gm/cc
DTM	Sonic Matrix Travel Time	us/ft
CEC	Cationic Exchange Capacity	meq/gm

MGSPC12.DAT contains various computed parameters that are written when log data is entered rather than read from an input Data File. The parameters contained in MGSPC12.DAT can be used for quality control purposes and/or input parameter selection. MGSPC12.DAT also contains computed results that do not appear in the Analysis File and others do appear in the Analysis File.

These results can also be used for quality control and/or parameter selection. The following outputs for each log depth analyzed are displayed in MGSPC12.DAT:

Mnemonic	Description	Units
DPTH	Depth of Formation	Ft. or M
THTA	Ratio of Neutron Porosity to Density Porosity	v/v
CNLC	Compensated Neutron Log Environmentally Corrected LS units	v/v
CNLG	Neutron Log Environment, Matrix and Gas Corrected LS units	v/v
PHNG	Neutron Porosity Environment, Matrix and Gas Corrected	v/v
PHHR	Porosity from Sonic, Hunt-Raymer	v/v
PHIT	Total Porosity	v/v
RHOC	Density Log Environmentally Corrected	gm/cc
ROGC	Density Log Environment and Gas Corrected	gm/cc
PHDG	Density Porosity Environment, Matrix and Gas Corrected	v/v
VM	Variable Cementation Exponent (VM = M if not varied)	F=A/Φ**VM
NaClWA	Apparent Formation Water Salinity	ppm NaCl
RWA75	Apparent Formation Water Resistivity @ 75DegF	OhmM
RWA	Apparent Formation Water Resistivity @ Form. Temp.	OhmM
RHFL	In-Situ Mud Filtrate Density	gm/cc
RHMA	Apparent Matrix Density	gm/cc
DTMH	Apparent Matrix Travel Time from Hunt-Raymer	us/ft
PHIX	Neutron Density Crossplot Porosity	v/v
VSGR	Volume of Shale from Gamma Ray	v/v
VSNE	Volume of Shale from Neutron Log	v/v
VSND	Volume of Shale from Neutron and Density Logs	v/v
RHMN	In-Situ Methane Density, Minimum Hydrocarbon Density	gm/cc
NaClFA	Apparent Filtrate Salinity	ppm NaCl
RMFA75	Apparent Filtrate Resistivity @ 75 DegF	OhmM
RMFA	Apparent Filtrate Resistivity @ Form. Temp.	OhmM
PHIR	Porosity from Resistivity	v/v
VSH	Volume of Shale	v/v
DTMA	Apparent Matrix Sonic Travel Time	us/ft
PHSN	Sonic Neutron Crossplot Porosity	v/v
SWU	Unlimited and Un-corrected Water Saturation Undisturbed Zone	v/v
SXOU	Unlimited and Un-corrected Water Saturation Invaded Zone	v/v
ROHY	In-Situ Hydrocarbon Density	gm/cc
SWIR	Irreducible Water Saturation from SW & BVIR, SW Lower Limit	v/v

ADDITIONAL PARAMETERS

Additional parameters may be computed internally by the program should the user not provide all of the requested input parameters. The following table list those parameters which may be computed and the inputs which are used. Note that the user may be prompted for certain inputs if they are not available in the Parameters File.

Mnemonic	Description	Units
TGRD	May be computed from BHT MST DPTH	DegF/100Ft
RW75	May be computed from SSP RMF75 and thin bed corrected from RT RM75	Ohm-M
RMF75	May be computed from RM75 WMUD	Ohm-M
RHFL	Is computed from RMF75	gm/cc

R_w at formation temperature is derived from the SP as follows:

$$R_w = \frac{R_{weq} + 0.131 * 10^{\left[\frac{1}{Log_{10}(FT/19.9)}\right]-0.2}}{-0.5 * R_{weq} + 10^{\left[0.0426/Log_{10}(FT/50.8)\right]}} \qquad where$$

$$R_{weq} = R_{mf} * \left[10^{\frac{SSP}{(60.0+0.133*FT)}}\right] \qquad and$$

$$SSP = SP * \left[\frac{\left(\left(4.0 * \left(\frac{R_t}{R_m} + 2.0\right)\right)^{0.274}\right) - 1.5}{\left(H - \left(\left(\frac{R_t}{R_m} + 11.0\right) \Big/ 0.65\right)^{0.165}\right) - 0.10} + 0.95\right]$$

FT is formation temperature in DegF and H is the formation's height in feet. When H is large the SP correction to SP is minimal. SSP=SP**CorrectionFactor* is applied under the appropriate conditions.

VSH OPTIONS

Various volume of shale from Gamma Ray equations are also available which can be changed during program execution or by editing the Parameters File. First, a Gamma Ray Index, GRI, is computed from GRSH and GRMA (*GRcl)* and GR as follows:

$$GRI = \frac{GR - GRcl}{GRsh - GRcl} \quad where \quad 0 < GRI \le 1.0$$

The available options [MGSPC - Version 1.2] are:

VSH Equation Switch	VSH(GR) Equation
1	Clavier
2	Steiber 1 (Index=0.5)
3	Steiber 2 (Index=0.8)
4	Log-Log Correlation (R.T. Rajeswaran)
5	Larinov Correlation Ancient Rocks
6	Larinov Correlation Tertiary Rocks
7	Linear

The equations and the numbers corresponding to the VSH Equation Switch are:

$$Vsh = 1.70 - \sqrt{(3.38 - (GRI + 0.7)^2} \qquad (1)$$

$$Vsh = 0.5 * GRI/(1.5 - GRI) \qquad (2)$$

$$Vsh = 0.8 * GRI/(1.8 - GRI) \qquad (3)$$

$$Log_{10}(Vsh) = \left(3.0 - \frac{3.0 * Log_{10}(1 + GRsh - GRcl)}{(Log_{10}(1 + GRsh - GRcl) - 1)} + \frac{3.0 * (1 + Log_{10}(GRI))}{(Log_{10}(1 + GRsh - GRcl) - 1)} \right) \quad (4)$$

$$Vsh = 0.3333 * (2.0^{(2.0 * GRI)} - 1.0) \quad (5)$$

$$Vsh = 0.0833 * (2.0^{(3.701 * GRI)} - 1.0) \quad (6)$$

$$Vsh = GRI \quad (7)$$

The Log-Log Correlation was developed for use in highly radioactive sandstones and is optimistic with respect to V_{sh} . Volume of shale computed from Neutron -x- Density and Neutron are:

$$Vsh_{ND} = \frac{\Phi_N - \Phi_D}{\Phi_{Nsh} - \Phi_{Dsh}}$$

$$Vsh_N = \frac{\Phi_N - \Phi_{Ncl}}{\Phi_{Nsh} - \Phi_{Ncl}}$$

The final V_{sh} is the minimum of the positive values as determined from Gamma Ray, Neutron and Neutron-x-Density.

POROSITY DETERMINATION

Various equations are used within the program in a hierarchy (see Appendix Three) to determine the total porosity, Φ_T , PHIT, and subsequently, the final value of effective porosity, Φ , PHIE.

Environmental (i.e. chart book) corrections are applied where applicable to each input log before a determination of porosity from that log is made. The porosity determined from Resistivity, Neutron, Density, Sonic (Hunt-Raymer), Neutron-x-Sonic and Neutron-x-Density is represented as follows:

$$\Phi_R = \left(\frac{R_t}{A * R_w} \right)^M$$

$$\Phi_N = \Phi_{N\ Corrected}$$

$$\Phi_D = \frac{\rho_{ma} - \rho_{\ Corrected}}{\rho_{ma} - \rho_{fl}}$$

$$\Phi_S = K_{HR} * \left(1 - \frac{\Delta T_{ma}}{\Delta T} \right) \quad where\ K_{HR} \approx 0.625;\ \text{In MGSPC;}\ K_{HR} = f\ (\Delta T\ ,\ \Delta T_{ma})$$

Φ_{NS} = *Algorithms for 1995 Schlumberger Chart CP-2b* [2]

2 Appendix Four shows Schlumberger Chart CP-2b. (Courtesy of http://www.connect.slb.com)

Φ_{ND} = *Algorithms for 1995 Schlumberger Chart CP-1c* [3]

The subscript "*Corrected* " for the Neutron, implies environmental and matrix corrected and for the Density implies environmentally corrected. Total porosity, Φ_T , PHIT, is derived according to the hierarchy as in **Appendix Three**; Neutron -x- Density is the first priority and Resistivity is the last.

$$\Phi_T = \Phi_R \text{ or } \Phi_N \text{ or } \Phi_D \text{ or } \Phi_S \text{ or } \Phi_{NS} \text{ or } \Phi_{ND}$$

Effective porosity, Φ , PHIE, is derived from the various logs and the volume of shale.

$$\Phi = f(\Phi_R \text{ or } \Phi_N \text{ or } \Phi_D \text{ or } \Phi_S \text{ or } \Phi_{NS} \text{ or } \Phi_{ND} \text{ and } V_{sh})$$

The effective porosity from Resistivity, Neutron, Density, Sonic (Hunt-Raymer), Neutron-x-Sonic and Neutron-x-Density is represented as follows:

$$\Phi = \Phi_R * (1 - V_{sh})$$

$$\Phi = \frac{\Phi_{N\ Corrected} - \Phi_{Nma} * (1 - V_{sh}) - \Phi_{Nsh} * V_{sh}}{1 - \Phi_{Nma}}$$

$$\Phi = \frac{\rho_{ma} * (1 - V_{sh}) + \rho_{sh} * V_{sh} - \rho_{\ Corrected}}{\rho_{ma} - \rho_{fl}}$$

$$\Phi = K_{HR} * \left[\left(1 - \frac{\Delta T_{ma}}{\Delta T} \right) - V_{sh} * \left(1 - \frac{\Delta T_{ma}}{\Delta T_{sh}} \right) \right]$$ $K_{HR} \approx 0.625$; in MGSPC; $K_{HR} = f(\Delta T , \Delta T_{ma})$

$\Phi = f(\Phi_N \text{ and } \Phi_S \text{ and } V_{sh})$ and *Algorithms for 1995 Schlumberger Chart CP-2b*

$\Phi = f(\Phi_N \text{ and } \Phi_D \text{ and } V_{sh})$ and *Algorithms for 1995 Schlumberger Chart CP-1c*

The hierarchy as shown in Appendix Three determines the final effective porosity. In the determination of the final effective porosity, "bad hole logic" is applied. Both the total and effective porosity derivations default to those as derived from the sonic log input, provided it exists, when the difference between the caliper input, CLP, and the bit size input, BTSZ, exceeds the caliper limit, CLIM. Also, the V_{sh} value defaults to that as determined from the Gamma Ray.

When the presence of hydrocarbons is detected from the log input values and intermediate computations, i.e. Neutron Porosity < Density Porosity and $S_{xo}<1$ or $S_w<1$, a hydrocarbon iteration loop is executed. This loop performs the excavation effect and hydrocarbon effect corrections to the neutron porosity and hydrocarbon effect corrections for the density log.

[3] Appendix Five shows Schlumberger Chart CP-1c (Courtesy of http://www.connect.slb.com)

The excavation effect correction for the Neutron porosity is:

$$\Delta\Phi_{N\ Excvtn} = \left(\frac{\rho_{ma}}{2.65}\right)^2 * \left(2.0 * \Phi^2 * S_{wh} + 0.4 * \Phi\right) * \left(1 - S_{wh}\right)$$

$$S_{wh} = \left(1 - S_{xo}\right) * \left[9.0 * \rho_{hyd} * \left(0.15 + 0.2 * (0.9 - \rho_{hyd})^2\right)\right] + S_{xo} * \rho_{mf} * \left(1 - \mathrm{P}\right)$$

$$\mathrm{P} = ppm\ NaCl\ \ Mud\ \ Filtrate / 10^6$$

The hydrocarbon correction to the Neutron porosity is:

$$\Delta\Phi_{N\ Hyd} = \Gamma * \Phi * \left(1 - S_{xo}\right) * \left[\frac{\rho_{mf} * \left(1 - \mathrm{P}\right) - 2.2 * \rho_{hyd}}{\rho_{mf} * \left(1 - \mathrm{P}\right)}\right] \qquad for\ \ \rho_{hyd} \le 0.25$$

$$\Delta\Phi_{N\ Hyd} = \Gamma * \Phi * \left(1 - S_{xo}\right) * \left[\frac{\rho_{mf} * \left(1 - \mathrm{P}\right) - \left(0.30 + \rho_{hyd}\right)}{\rho_{mf} * \left(1 - \mathrm{P}\right)}\right] \qquad for\ \ \rho_{hyd} \ge 0.25$$

$0.1 < \Gamma < 2.5$ (depends on logging tool type, Γ =1.3 for CNL)

The hydrocarbon correction to the Density log is:

$$\Delta\rho_{Hyd} = \Omega * \left[1.07 * \Phi * \left(1 - S_{xo}\right) * \left((1.11 - 0.15 * \mathrm{P}) * \rho_{mf} - (1.11 * \rho_{hyd} + 0.03)\right)\right]$$

$$for\ \ \rho_{hyd} \le 0.23$$

$$\Delta\rho_{Hyd} = \Omega * \left[1.07 * \Phi * \left(1 - S_{xo}\right) * \left((1.11 - 0.15 * \mathrm{P}) * \rho_{mf} - (1.24 * \rho_{hyd})\right)\right]$$

$$for\ \ \rho_{hyd} \ge 0.23$$

$0.1 < \Omega < 2.5$ (depends on logging tool type, Ω =1.0 for FDC)

The inputs to this hydrocarbon iteration loop are the initial values of porosity determined from the Neutron and Density, Φ, initial values of S_w, , S_{xo} , V_{sh} and ρ_{hyd} . The loop iterates until a convergence is obtained which yields the final values of Φ, S_w, , S_{xo} , V_{sh} and [illegible] . In the absence of a flushed zone resistivity measurement, R_{xo} , then $S_{xo} = S_w^{1/5}$, an empirical relationship.

WATER SATURATION EQUATIONS

Water saturation equations have been developed for many years stemming from the fundamental Archie water saturation equation. These developments have primarily been involved with handling the effects of clay on the conductivity response of the formation. They have lead to the concept and application of total porosity instead of the conventional effective porosity. Core derived CEC (Cationic Exchange Capacity, meq/gm) measurements and Q_v (counter-ion charge per unit pore space volume, meq/cm^3) derivations, have been incorporated and applied to further enhance the accuracy of S_w . The water saturation equation options in MGSPC are a representation of this evolution up to the incorporation of CEC measurements. Facsimile logs are seldom accompanied by CEC data. Some important equations involving Q_v are listed herein for reference and comparison. The SANDWICH model, developed by Shell to address the structural affect of shales, is described.

The listing of the water saturation equations here depict the formation's contribution to its electrical conductivity C_t , or $1/R_t$. R_t and R_{xo} are derived from resistivity logging tool measurements using the appropriate "tornado chart". The water saturation equations and their solutions used in MGSPC are written in terms of fundamental quantities for the depiction of the contribution of each variable to the formation's electrical conductivity.

Various water saturation equation options are available. The input Water Saturation Equation Switch is contained in the Parameters File and can be changed during program execution to a different value and hence a different water saturation computed for comparison purposes etc. The available options [MGSPC - Version 1.2] are: [4]

Water Saturation Equation Switch	SW (& SXO) Equation
1	Archie
2	Simandoux - Total Shale
3	Simandoux - Laminar Shale
4	VSH**2 Modified Simandoux - Total Shale
5	Modified Simandoux - Total Shale
6	Indonesian (Poupon & Leavaux)
7	Dispersed Shale (Schlumberger)
8	Laminated Shale (Poupon)
9	Dual Water (Coates & Dumanoir)
10	Juhasz
11	Waxman-Smits
12	Modified Waxman-Smits
13	Sandwich (Sarawak Shell)
14	Conductive Mineral

The water saturation equations and their Equation Switch numbers are:

[4] The equations and solutions written here are in a practical form and may differ from those found in the References. The petrophysicist takes the "Experimental and Theoretical" and applies it in the real world. The literature, at times, seems not to lend itself to practical application. All of the parameters needed to apply the water saturation equations in MGSPC can be ascertained and/or estimated with reasonable accuracy from a complete suite of log data and a basic knowledge of the depositional / lithological environment.

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w} \tag{1}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w} + \frac{V_{sh} * S_w}{R_{sh}} \tag{2}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w * (1 - V_{sh})} + \frac{V_{sh}^2 * S_w}{R_{sh}} \tag{3}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w * (1 - V_{sh}^2)} + \frac{V_{sh}^2 * S_w}{R_{sh}} \tag{4}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w * (1 - V_{sh})} + \frac{V_{sh} * S_w}{R_{sh}} \tag{5}$$

$$\frac{1}{R_t} = \left[\left(\frac{\Phi^M}{A * R_w} \right)^{0.5} + \frac{(V_{sh})^{(1-0.5*V_{sh})}}{(R_{sh})^{0.5}} \right]^2 * S_w{}^N \tag{6}$$

$$\frac{1}{R_t} = \frac{\Phi_T^M * S_{wt}}{A} * \left(\frac{V_{sh}}{R_{sh}} + \frac{S_{wt} - V_{sh}}{R_w} \right) \quad and \quad S_w = \frac{S_{wt} - V_{sh}}{1 - V_{sh}} \tag{7}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w * (1 - V_{sh})^{(M-1)}} + \frac{V_{sh}}{R_{sh}} \tag{8}$$

$$C_t = \frac{\Phi_T^M S_{wt}^N}{A} * \left[\left(1 - \frac{S_{wb}}{S_{wt}} \right) * C_{wf} + C_{wb} * \left(\frac{S_{wb}}{S_{wt}} \right) \right] \tag{9}$$

$$C_t = \frac{\Phi_T^M * S_{wt}^N}{A} * \left[\frac{1}{R_{wf}} + \frac{Q_{Vn}}{S_{wt}} * \left(\frac{1}{R_{wb}} - \frac{1}{R_{wf}} \right) \right] \tag{10}$$

$$C_t = \left(\frac{\Phi_T^{M^*} * S_w^N}{A^* * R_{wf}} \right) * \left(\frac{1 + R_{wf} * B * Q_v / S_w^{N-1}}{1 + R_{wf} * B * Q_v} \right) \tag{11}$$

$$C_t = \frac{\Phi_T^{M^*} * S_w^N}{A^*} * \left[C_{wf} + \left(\frac{B * Q_v}{S_w} \right) \right] \tag{12}$$

$$\frac{1}{R_{app}} = \frac{\Phi_T^{M^*} * S_{wt}^N}{A^* * R_{wf}} * \left[1 + \frac{R_{wf} * Q_{Vns}}{S_{wt}} \right] \tag{13}$$

$$\frac{1}{R_t} = \frac{\Phi^M * S_w{}^N}{A * R_w * (1 - V_{sh} - V_{cm1})} + \left(\frac{V_{sh}^{1.5}}{R_{sh}} + \frac{V_{cm1}}{R_{cm1}} \right) * S_w \qquad (14)$$

Note that for each water saturation equation, V_{sh} = 0.00 reduces it to Archie's Equation. Also note that the Dispersed Shale and the Dual Water equations utilize total porosity, Φ_T , instead of effective porosity, Φ. In the Dual Water equation: $C_t=1000/R_t$, $C_{wf}=1000/R_w$ and $C_{wb}=1000/R_{sh}*\Phi_{Tsh}^2$. The saturation exponent, N, has been set equal to 2.0 in the Dispersed Shale and the Dual Water saturation equations. The variation in the saturation exponent, N, is in the format $S_w = \sqrt{S_w^N}$.

DUAL WATER SATURATION EQUATION

The Dual Water Saturation was developed by Coates et. al. to better handle the clay conductivity associated with shaley sands in the Gulf of Mexico. The concepts of clay bound water and free water components are utilized.

$$C_t = \frac{\Phi_T^M S_{wt}^N}{A} * \left[\left(1 - \frac{S_{wb}}{S_{wt}} \right) * C_{wf} + C_{wb} * \left(\frac{S_{wb}}{S_{wt}} \right) \right]$$

$$S_{wt} = \frac{S_{wb} * (C_{wf} - C_{wb})}{2 * C_{wf}} + \left[\left(\frac{A * C_t}{C_{wf} * \Phi_T^M} \right) + \left(\frac{S_{wb} * (C_{wf} - C_{wb})}{2 * C_{wf}} \right)^2 \right]^{0.5}$$

$$S_{wb} = \frac{\Phi_{Tsh} * V_{sh}}{\Phi_T}$$

$$S_w = \frac{S_{wt} - S_{wb}}{1 - S_{wb}}$$

CEC SATURATION MODELS

The Waxman-Smits equation involves core derived CEC, Cationic Exchange Capacity, (meq/gm) measurements. As foundation, Waxman et. al. stated: "From labarotory measurements … the effective concentration of clay exchange cations increase in proportion to the decrease in water saturation." The Waxman-Smits equation can be written as follows: [5]

$$C_t = \frac{\Phi_T^{M^*} * S_w^N}{A^*} * \left[C_{wf} + \left(\frac{B * Q_v}{S_w} \right) \right]$$

5

ion-equivalent	the amount of charge in 1 mole of protons ($6.023*10^{23}$ protons$*1.6*10^{19}$ coulombs/proton)	
meq	milli ion-equivalent	(a unit of charge)
Q_v	clay counter-ion charge per unit volume of pore space	(meq/cm^3)
CEC	cationic exchange capacity	(meq / gm)
B	equivalent clay counter-ion conductivity	(mho/m / meq/cm^3)
$B*Q_v$	conductivity of the clay counter-ions	(mho/m)

$$S_w^{\ N} = \left[\left(\frac{A^* * R_w}{\Phi_T^{M^*} * R_t} \right) * \left(\frac{1 + R_w * B * Q_v}{1 + R_w * B * Q_v / S_w^{N-1}} \right) \right]$$

$$Q_V = \frac{V_{dry\_clay} * \rho_{dry\_clay} * CEC_{dry\_clay}}{\Phi_T} \qquad \text{(Theoretical)}$$

Q_v = counter-ion charge per unit pore volume (meq/cm^3) which depends upon the amount and type of clay and is derived from core measurements of CEC. Q_v is related to wet clay porosity response of a particular clay type. Average values for CEC of common clays are shown in the following table:

Clay Type	Illite	Glauconite	Kaolinite	Chlorite	Smectite	
Density	2.79	2.96	2.59	2.82	2.78	gm/cc
Wet Porosity	.156	.156	.058	.101	.425	v/v
CEC	0.25	0.23	0.09	0.15	1.00	meq/gm

B = equivalent counter-ion conductivity (mho-m/meq/cm^3). B can be determined from the following empirical relationship:

$$B = \frac{\left(-1.28 + 0.225 * T - 4.059 * 10^{-4} * T^2\right)}{\left(1 + (0.045 * T - 0.27) * R_w^{1.23}\right)} \qquad \textit{where T is temperature in DegC}$$

As a practical application, Q_v can be approximated using the following relationship:

$$Q_V = \frac{(1 - \Phi) * \rho_{ma} * CEC * V_{sh}}{\Phi_T} \qquad \text{(Practical)}$$

A^* and M^* (i.e. A and M corrected for shaliness) are related to conventional A and M as follows:

$$F^* = \frac{A}{\Phi^M} * \left(1 + B * Q_v * R_w\right)$$

$$F^* = \frac{A^*}{\Phi_T^{M^*}}$$

$$Log_{10} F^* = -M^* * Log_{10} \Phi_T + Log_{10} A^*$$

Therefore, as a practical matter, A^* and M^* can determined from the above equation using core derived measurements of CEC, (derived Q_v), A , M and Φ_T .

The Modified Waxman-Smits Water Saturation is as follows:

$$C_t = \frac{\Phi_T^{M^*} * S_w^N}{A^*} * \left[C_{wf} + \left(\frac{B * Q_v}{S_w} \right) \right]$$

$$S_w^{\ N} = \left(\frac{A^* * R_{wf}}{\Phi_T^{M^*} * R_t} \right) * \left(\frac{S_w}{S_w + R_{wf} * B * Q_v} \right)$$

Juhasz incorporates the concepts of the Waxman-Smits equation and applies them without the use of core derived CEC data via a "Normalized Q_V ", Q_{Vn} . The Juhasz equation is:

$$\frac{1}{R_t} = \frac{\Phi_T^M * S_{wt}^N}{A} * \left[\frac{1}{R_{wf}} + \frac{Q_{Vn}}{S_{wt}} * \left(\frac{1}{R_{wb}} - \frac{1}{R_{wf}} \right) \right]$$

$$S_{wt}^N = \frac{A}{\Phi_T^M * R_t} * \left[\frac{S_{wt} * R_{wb} * R_{wf}}{Q_{Vn} * R_{wf} + (S_{wt} - Q_{Vn}) * R_{wb}} \right]$$

$$Q_{Vn} = \frac{V_{sh} * \Phi_{Tsh}}{\Phi_T}$$

$$R_{wb} = \frac{R_{sh} * \Phi_{Tsh}^M}{A}$$

$$S_w = \frac{S_{wt} - Q_{Vn}}{1 - Q_{Vn}}$$

$$\Phi = \Phi_T * (1 - Q_{Vn})$$

The solution to Waxman-Smits equation and the Juhasz equation involve iterative mathematical programming techniques since Sw remains on both sides of the equation. The applications of these CEC water saturation equations involve an iterative solution as in MGSPC12.EXE.

SANDWICH MODEL

Sarawak Shell developed the "Sand With Intercalated Clay and Hydrocarbon" (SANDWICH) model which handles the shale (clay) distribution as different fractions of clay textures which are comprised of dispersed, structural and laminated components (MGSPC - Version 1.2). The different types of shales are quantified using a neutron and density porosity crossplot or total porosity and V_{sh} crossplot (Thomas-Steiber) [6] as a portion of the total volume of shale:

$$V_{sh} = V_{disp} + V_{struc} + V_{lam}$$

The total volume of shale is determined from the Neutron log and an initial total porosity:

$$V_{sh} = \frac{\Phi_N - \Phi_T}{\Phi_{Nsh} - \Phi_{Tsh}}$$

6 Tohmas, E.C. and Stieber, S.J., "The Distribution of Shale in Sandstones and its Effect Upon Porosity," SPWLA Symposium Transactions, June, 1975.

I.	Laminated Shale	$\Phi_T = \Phi_S - V_{sh}*(\Phi_S - \Phi_{sh})$		
II.	Dispersed (Pore Filling)	$\Phi_T = \Phi_S - V_{sh}*(1 - \Phi_{sh})$	for	$V_{sh} < \Phi_S$
III.	Dispersed (Grain Replacing)	$\Phi_T = V_{sh}*\Phi_{sh}$	for	$V_{sh} > \Phi_S$
IV.	Structural (Grain Replacing)	$\Phi_T = \Phi_S + V_{sh}*\Phi_{sh}$	for	$V_{sh} < 1 - \Phi_S$
V.	Structural (Pore Filling)	$\Phi_T = 1 - V_{sh}*(1 - \Phi_{sh})$	for	$V_{sh} < 1 - \Phi_S$

The total porosity (using corrected density, ρ_b) of the sand matrix (Φ_{Tsd}), is determined via:

$$\Phi_{Tsd} = \frac{\rho_b - \rho_{ma}}{\rho_{fl} - \rho_{ma}}$$

The total porosity of the formation is corrected for laminated shale as follows:

$$\Phi_T = \Phi_{Tsd} * (1 - V_{lam}) + \Phi_{Tsh} * V_{lam}$$

The apparent true formation resistivity (R_{app}) is modeled consistent with the laminated shale geometry using serial and parallel resistivity components, (R_{srl} and R_{prl} respectively), the true resistivity of the sand and shale (R_{sd} and R_{sh}) and an apparent formation dip angle (α) :

$$R_{srl} = V_{lam} * R_{sh} + (1 + V_{lam}) * R_{sd}$$

$$\frac{1}{R_{prl}} = \frac{V_{lam}}{R_{sh}} + \frac{(1 - V_{lam})}{R_{sd}}$$

$$\frac{1}{R_{app}} = \sqrt{\frac{1}{R_{prl}^2} COS^2\alpha + \frac{1}{R_{prl} * R_{srl}} SIN^2\alpha}$$

The Juhasz equation is utilized with dispersed and structural shale volumes only:

$$\frac{1}{R_t} = \frac{\Phi_T^{M^*} * S_{wt}^N}{A} * \left[\frac{1}{R_{wf}} + \frac{Q_{Vn}}{S_{wt}} * \left(\frac{1}{R_{wb}} - \frac{1}{R_{wf}} \right) \right] \quad \text{(Juhasz)}$$

$$\frac{1}{R_{app}} = \frac{\Phi_T^{M^*} * S_{wt}^N}{A^* * R_{wf}} * \left[1 + \frac{R_{wf} * Q_{Vns}}{S_{wt}} \right] \quad \text{(Sandwich)}$$

$$Q_{Vns} = \left(\frac{1}{R_{wb}} - \frac{1}{R_{wf}} \right) * \left(\frac{(V_{disp} + V_{struc}) * \Phi_{Tsh}}{\Phi_T} \right)$$

$$R_{wb} = \frac{R_{sh} * \Phi_{Tsh}^{M^*}}{A^*}$$

$$S_{wt}^N = \frac{A * \Phi_T^{M^*}}{R_t} * \left[\frac{S_{wt} * R_{wb} * R_{wf}}{Q_{Vn} * R_{wf} + (S_{wt} - Q_{Vn}) * R_{wb}} \right] \quad \text{(Juhasz)}$$

$$S_{wt}^N = \frac{A^* * R_{wf}}{\Phi_T^{M^*} * R_{app} * (1 + R_{wf} * Q_{Vns} / S_{wt})} \quad \text{(Sandwich)}$$

The complexity of water saturation equations is certainly a continuing development. These equations and associated theories require good well log and core derived data and an integrated approach.

HYDROCARBON DENSITY

The computation of In-Situ Hydrocarbon Density, ROHY, is only attempted when there exists as input log data both a Neutron and Density log. The value computed for ROHY, depends on the accuracy of the input log data and parameters. The algorithm used is:

$$\rho_{hyd} = \frac{\theta - 1*(1 - S_{xo})*\left[\left(\frac{\rho_{mf}*(1-\mathrm{P})+0.2}{\rho_{mf}*(1-\mathrm{P})}\right)*\beta + \frac{1.07*\theta*(1.11-0.15*\mathrm{P})*\rho_{mf}}{\rho_{ma}-\rho_{mf}}\right]}{(1 - S_{xo})*\left[\frac{1.5*\beta}{\rho_{mf}*(1-\mathrm{P})} + \frac{1.23*\theta}{\rho_{ma}-\rho_{mf}}\right]}$$

$$\theta = \frac{\Phi_{N\ Corrected}}{\Phi_{D\ Corrected}}\ , \quad \mathrm{P} = ppm\ NaCl\ Mud\ Filtrate / 10^6\ , \quad 0.1 < \beta < 2.5$$

ROHY defaults to RHFL if no Neutron and Density log is input. ROHY has as a lower limit the in-situ methane density and an upper limit of RHFL. β is a function of the Neutron tool type used, e.g. CNL or SNP; for MGSPC, the conventional CNL tool and NPHI measurement are assumed to be input.

LITHOLOGICAL MODEL

The basic and simple lithological model of Shale, Matrix, Porosity with Formation Water and Hydrocarbon is the model used in MGSPC. Whether or not the shale (clay) is laminated, structural or dispersed and which V_{sh} and S_w equation options are applicable relies upon the user's interpretation. Knowledge of the rock's porosity and shale type should be ascertained from available sources. The apparent matrix density, RHMA, apparent matrix travel time, DTMA, and/other log responses and intermediate results should also yield the identity of the formation's lithology when interpreted correctly. The MGSPC program is applicable in carbonate formations also and incorporates the use of a variable cementation exponent, M .

Variable M is input by an appropriate value for M in the Parameters File:

M Value in Parameters File	M Equation	M Option #
< 10.0	Use Input Parameter Value for Constant M	1
= 20.0	Low Porosity Carbonates (Shell)	2
= 30.0	Vuggy Porosity Carbonates (Nugent)	3
= 40.0	Fractured Porosity Carbonates (Rasmus)	4

The variable M equations which may used to input the value for M and M Option # are:

$$M = M\ from\ Parameters\ File \tag{1}$$

$$M = 1.87 + \frac{0.019}{\Phi} \tag{2}$$

$$M = \frac{2 * Log_{10}\Phi_S}{Log_{10}\Phi_T} \tag{3}$$

$$M = \frac{Log_{10}\left[\Phi_S^3 + \Phi_S^2 * (1 - \Phi_T) + (\Phi_T - \Phi_S)\right]}{Log_{10}\Phi_T} \tag{4}$$

The Hunt-Raymer sonic porosity is used for Φ_S in MGSPC - Version 1.2 .

PROGRAM CONTROL

During running of the program there are several options available so that the user can modify inputs, save a new Parameters File, recalculate the current depth reflecting parameter changes and to display information etc. The user can only utilize these Program Switches when they appear on the terminal screen in the prompt line. The Program Switch options [MGSPC - Version 1.2] are:

Program Switch	Explanation
2	Recalculate current depth all SWEQ's
1	Recalculate current depth interval
0	End this session of computations
-1	INPUT: A, M, N, SWEQ, GREQ
-2	INPUT: NLSH, RHSH, DTSH, RTSH, RXSH
-3	INPUT: RW75, RMF75, RMC75, RM75
-4	INPUT: RHOM, DTM, GRMA, GRSH
-5	INPUT: TGRD, MST, BTSZ, WMUD
-6	Enter Well Parms File_Name or <> to Create [7]
-7	Write New Parameters File? (Y, A or N)
-8	This Help Message
-9	List definitions of input parameters
-10	List definitions of input & output logs
-11	List definitions of GREQ & SWEQ equations

When the user is prompted for the INPUT as shown in the table Program Switch, then entering 0 (zero) for any parameter except where noted retains the already existing value of that parameter which is also displayed as part of the prompt. This reduces the amount of typing when some of the input parameters need not to be changed.

Should the user and/or the program call Program Switch: -7, then three options become available. The "Y" (Yes) option will prompt for the New Parameters File name and then write out the current parameters. The "A" (Apparent) option will write out the current parameters with the exception that apparent values, RWA @75DegF, RMFA @75DegF, RHMA and DTMA are written out for RW75, RMF75, RHOM and DTM respectively. The "N" (No) option returns to the program to normal execution.

PROGRAM FLOW

[7] <> means Enter key on the keyboard.

The logic of the program can be divided into that as seen and/or controllable by the user and the analysis sequence applied in the derivation of the output results. **Appendix Two** shows **Flow Chart One,** the flow diagram from the user's perspective.

Flow Chart One is relatively easy to follow. It is designed to be an overall guide for the user showing primarily the input steps, decision steps, options and questions and the point at which the new data, parameters and results are written out to their appropriate files. Note that the box "Enter New Data File Name" is executed only once; thereafter all input log data is written to the new Data File.

A few times through following Flow Chart One should be sufficient training in program execution. When going through the program execution, try to identify the progress through Flow Chart One.

Appendix Three shows **Flow Chart Two,** the log analysis computational aspects of MGSPC. Flow Chart Two depicts the major steps performed in Flow Chart One's box labeled "Perform Computations". Note that if one or more of the log inputs are entered as an absent value "-1" then the program acts accordingly with respect to those inputs that it has. One of the more complex functions performed by MGSPC is the hydrocarbon iteration loop which performs the critical hydrocarbon corrections to the porosity log inputs and derives an in-situ hydrocarbon density. This iteration loop is only applied when the presence of hydrocarbons is detected from the log input values and intermediate computations, i.e. Neutron Porosity < Density Porosity and $S_{xo}<1$ or $S_w<1$.

CONCLUSION

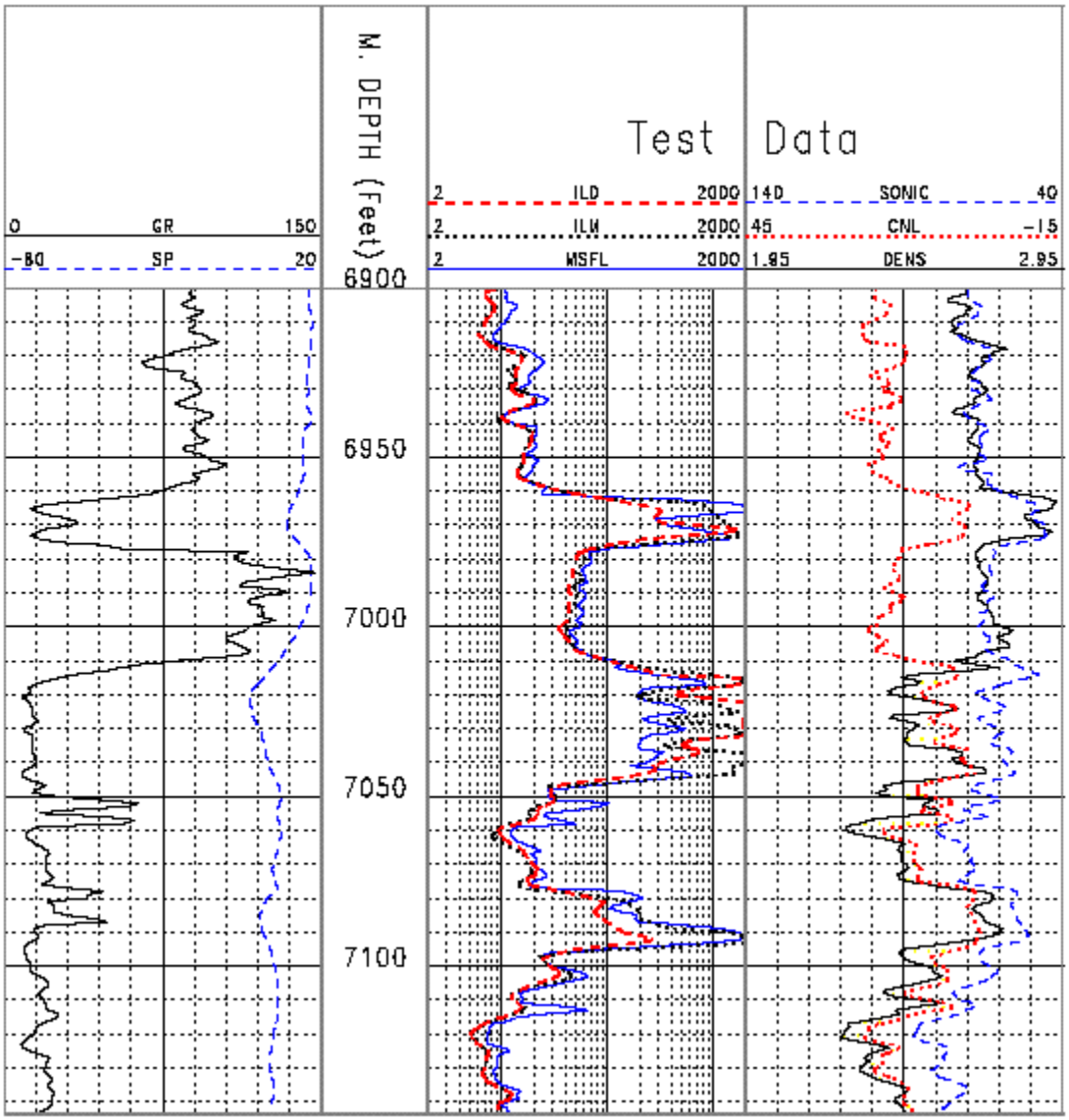
MGSPC - Version 1.2 is a very useful tool when applied diligently to a set of log derived data. It will save considerable time in performing log analysis computations and allows for the use of apparent values in the aid in determining the selection input parameters. There is minimum "error trapping" in the program, hence the user must be sure to input physical log and parameter data to avoid program disruption. The algorithms used have been tested and verified in a number of reservoir conditions and will yield reliable quantitative log analysis results when applied correctly.

The equations and algorithms presented herein are for as much for reference as for program documentation. They should be of benefit to those who may not have the time to research and study the literature and assimilate them. The way in which they are presented and written should engender an appreciation for the numerous input variables required to perform even the most fundamental petrophysical well log evaluation. It should be apparent that the determination of S_{xo} is as critical as that of S_w. . The assimilation, programming and testing of these equations and algorithms have taken considerable time and effort. To have written them down will be an aid in the understanding the basic concepts of how log analysis / petrophysical models in this program and those applicable on more advance computer systems perform their basic analytical function.

For the new petrophysicist venturing into quantitative formation evaluation, the ability to "experiment" with the many equation options and perform comparative computations will be beneficial and build a better understanding of the interrelationships of the input logs, parameters and analysis results.

TEST EXAMPLE

A test data set was used in a comparative analysis of Terrasciences II Version 6.0 (TSII) software and MGSPC12 utilizing equivalent evaluation models. An ASCII data set was used to input log data into TSII and as a Data File for MGSPC12. The input logs of this ASCII data set as loaded into TSII are shown in the log data plot below entitled Test Data.

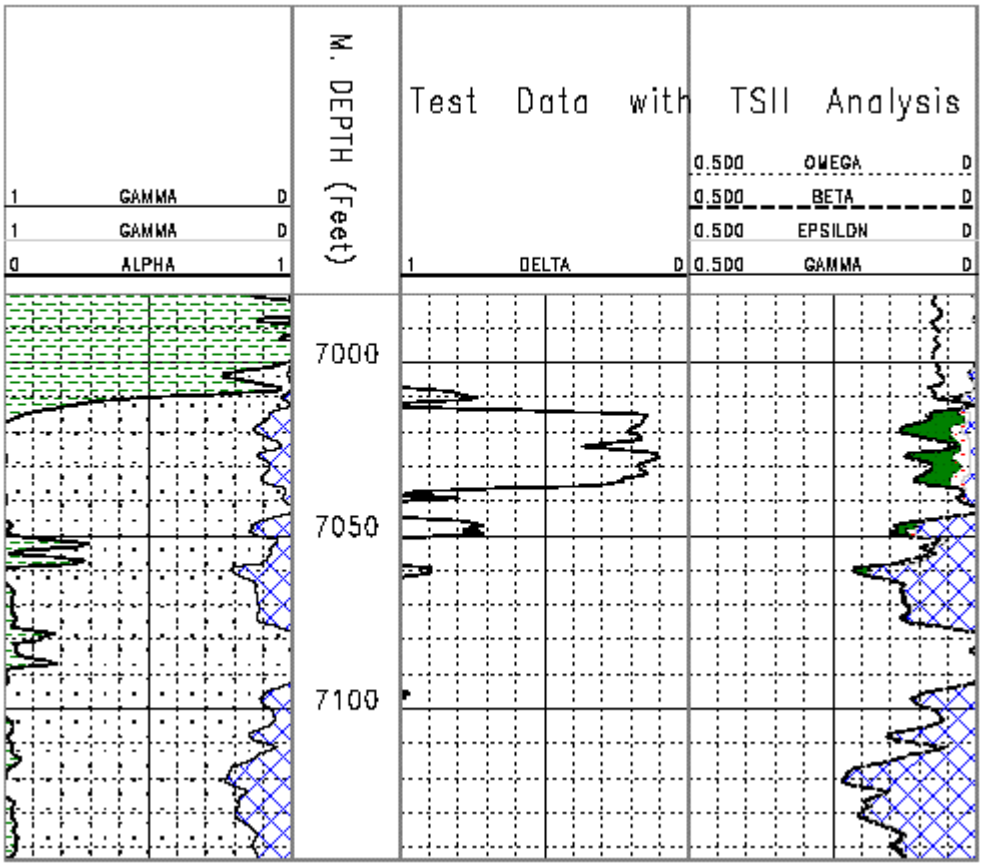


No log header data was readily available with the test data set. A reasonable and physical improvisation was made for the missing information and applied equally in TSII and MGSPC12. The log analysis was performed from 6980 to 7143 feet which encompasses a shale, hydrocarbon and water bearing zone.

The parameters used in the TSII Analysis are listed as they appear in the TSII control panel. The reader should refer to the Terrasciences manual for definitions and units of these parameters. The file has been edited with respect to the number of columns for display here as follows:

Following is the analysis results from TSII which is labeled Test Data with TSII Analysis:

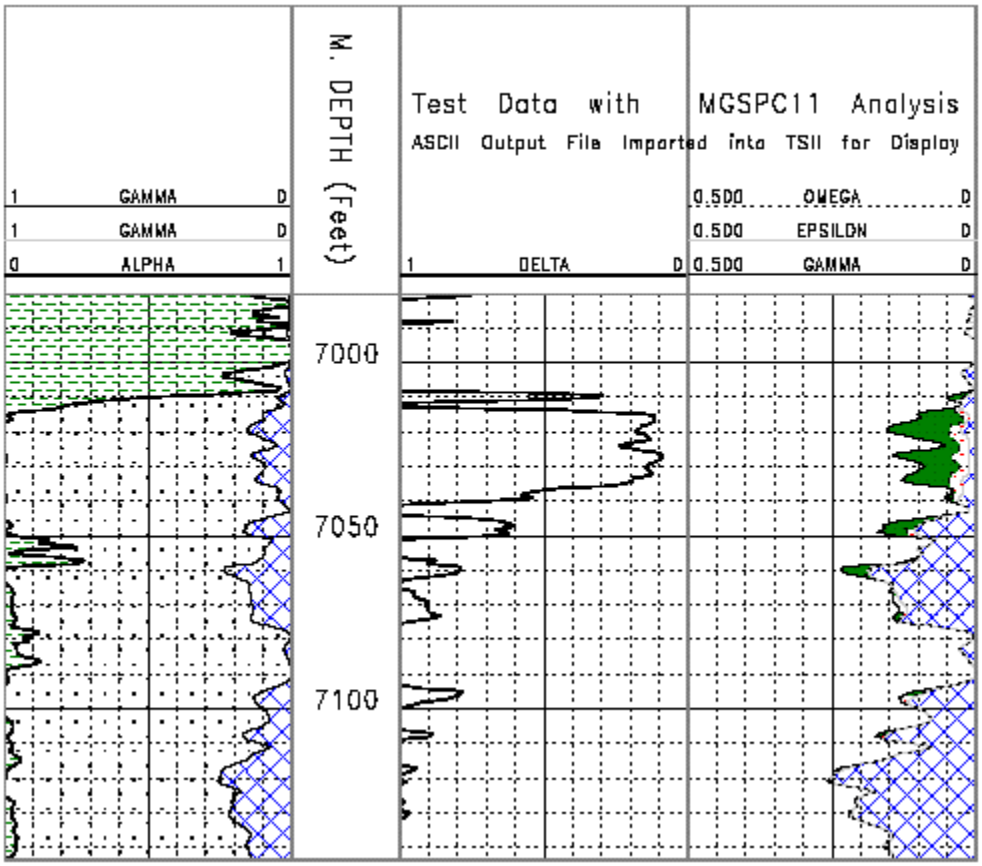
1	MINIMUM DEPTH	6900.000	26	FM SALINITY(PPM)	0.000
2	MAXIMUM DEPTH	7143.500	27	BH SALINITY(PPM)	0.000
3	DEPTH INCREMENT	0.500	28	STANDOFF (IL)	0.000
4	ELEVATION	NULL	29	STANDOFF (NEUT)	0.000
5	RMC	1.144	30	O.D. CASING(IN)	7.000
6	TRMC	75.000	31	WT. CASING(#/FT)	20.000
7	RM	1.175	32	TYPE OF MUD	0.000
8	TRM	75.000	33	AUTO CALI CORR	0.000
9	RMF	0.943	34	34=	NULL
10	TRMF	75.000	60	60=	NULL
11	RW	0.703	61	GR MATRIX	12.500
12	TRW	75.000	62	RHO MATRIX	2.650
13	BHT	165.000	63	DT MATRIX	55.500
14	MEAN SURF TEMP	80.000	64	CNL MATRIX	-6.000
15	T-GRADIENT	NULL	65	GR SHALE	117.500
16	ARCHIE A	1.000	66	RHO SHALE	2.700
17	ARCHIE M	2.000	67	DT SHALE	64.000
18	SAT EXP (N)	2.000	68	CNL SHALE	0.180
19	R SHALE	50.000	69	GR FLUID	20.000
20	TD	7200.000	70	RHO FLUID	1.000
21	X COORD	NULL	71	DT FLUID	189.000
22	Y COORD	NULL	72	CNL FLUID	1.000
23	CALIPER CHANNEL	18.000	73	DT MATRIX SHALE	64.000
24	BIT SIZE (IN)	8.500	74	74=	NULL
25	MUD WEIGHT(#/GL)	9.900	75	75=	NULL



Similarly, the following parameters where used in the MGSPC12 log analysis:

TGRD	1.200	NLSH	0.180
MST	80.000	RHSH	2.700
BTSZ	8.500	DTSH	64.000
WMUD	9.900	RTSH	50.000
RHOM	2.650	RXSH	60.000
DTM	55.500	A	1.000
GRMA	12.500	M	2.000
GRSH	117.500	N	2.000
RW75	0.703	SWEQ	9.000
RMF75	0.943	GREQ	1.000
RMC75	1.144	RM75	1.175

Following is the analysis results from MGSPC12 labeled Test Data with MGSPC12 Analysis:



The output ASCII Analysis File generated by MGSPC12 was loaded into TSII and displayed as shown. [8] Note that the Neutron log input has been changed to decimal units for input into MGSPC12. This comparison should be reasonable validation of the MGSPC12 program.

8 Terrasciences (TSII) uses a naming convention for its basic petrophysical analysis output which has been utilized in the above log analysis displays:

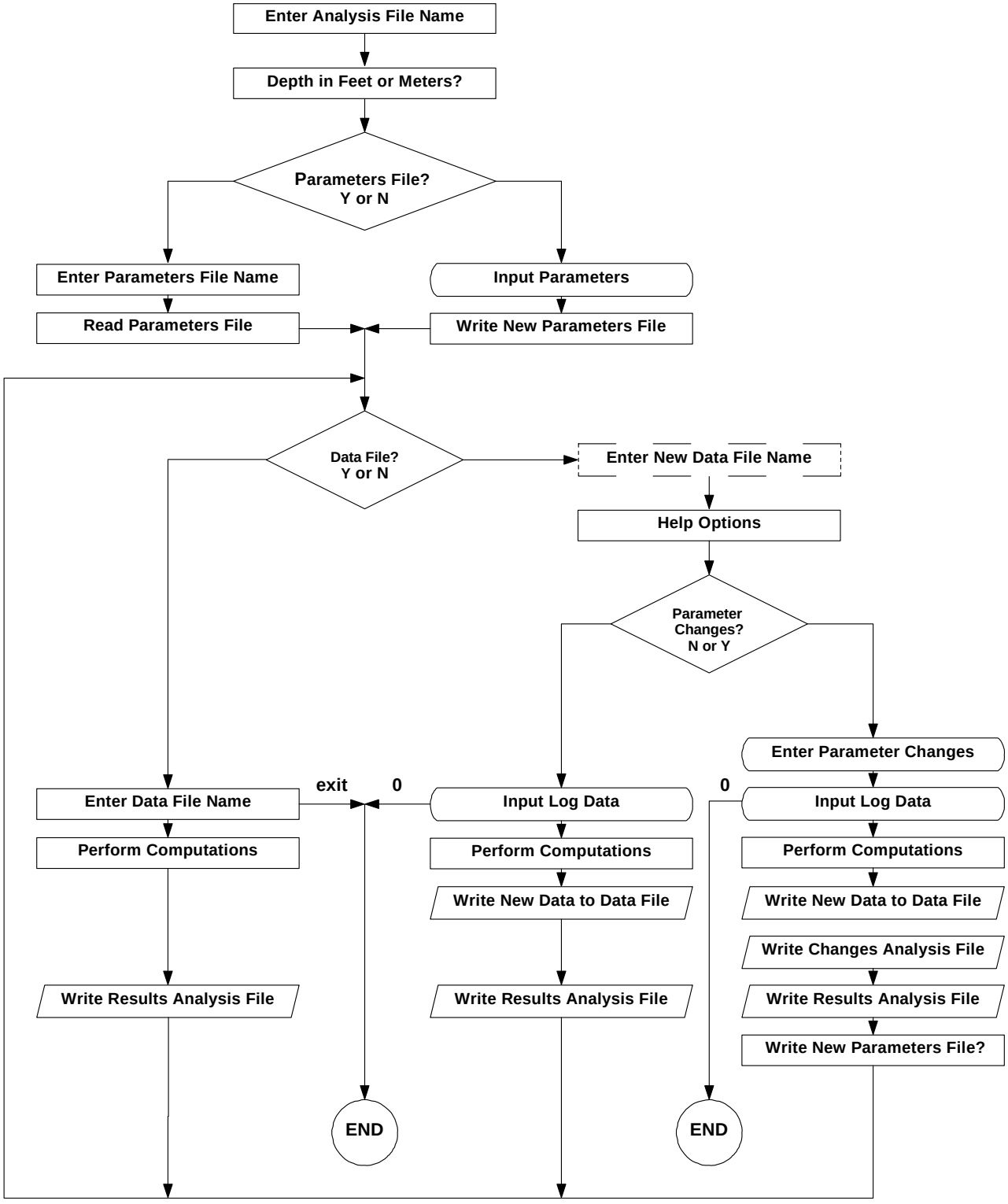
Vsh	ALPHA	Φ_T	BETA
Φ	GAMMA	$\Phi*S_w$	EPSILON
S_w	DELTA	$\Phi*S_{xo}$	OMEGA

APPENDIX ONE

The following are the FORTRAN FORMAT statements used to write out the ASCII files associated with MGSPC - Version 1.2 as noted:

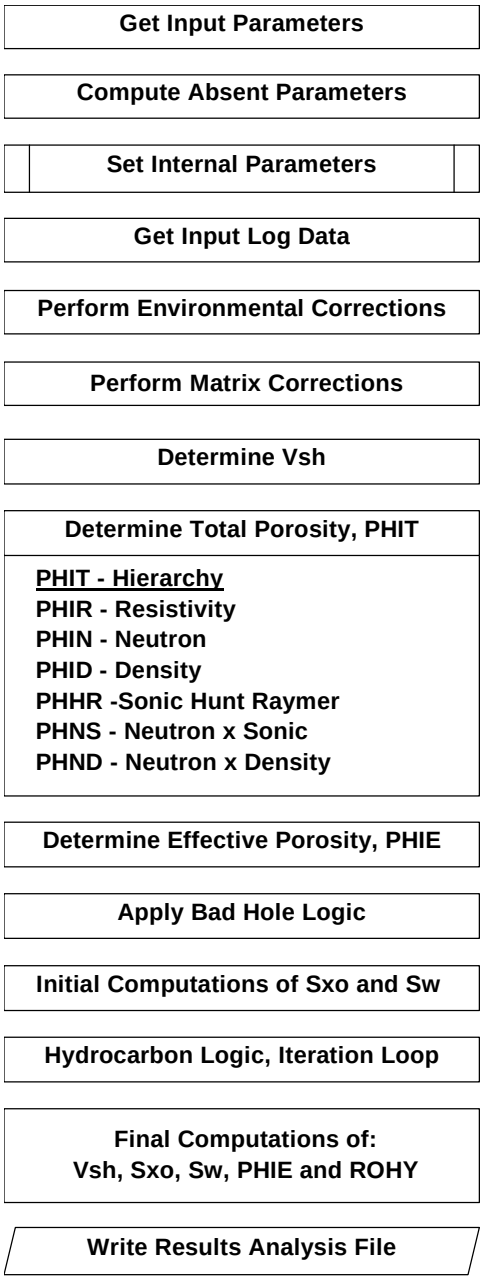
```
C       Parameters File
C
      FORMAT (A5,F8.3)
C
C       Analysis File (Header)
C
WRITE(9,23) WMUD,RTSH,RXSH,A,M,N,ISWEQ,IGREQ,BCP,DTFL,BTSZ,DTSH
23    FORMAT(2X,3(F5.1,1X),3(F5.2,1X),2(I4,2X),F5.2,1X,F5.1,1X,
     *           F7.2,1X,F5.1,1X)
C
C       Analysis File (Header)
C
      WRITE(9,25) RHOM,NLSH,RHSH,TGRD,MST,RW75,RMF75,RMC75,GRMA,GRSH,
     *           RHFL,DTM
25    FORMAT(2X,4(F5.3,1X),F5.1,1X,3(F5.3,1X),2(F5.1,1X),
     *           F7.3,1X,F5.1,1X)
C
C       Data File
C
      WRITE(7,53) DPTH,CLP,RT,RXO,RHOB,CNLS,GR,DLT,CLIM
53    FORMAT(1X,(F7.1,1X),(F8.3,1X),2(F8.2,1X),5(F8.3,1X))
C
C       MGSPC12.DAT
C
      WRITE(8,707) DPTH,THTA,CNLC,CNLG,PHNG,PHHR,PHIT,RHOC,ROGC,PHDG
707   FORMAT(1X,F7.1,1X,9(F6.3,1X))
C
C       MGSPC12.DAT
C
      WRITE(8,709) NCLW,RWA75,RWA,RHFL,RHMA,DTMH,PHIX,
     *           VSGR,VSNE,VSND,RHMN
709   FORMAT(1X,F8.0,4(F6.3,1X),(F6.1,1X),5(F6.3,1X))
C
C       MGSPC12.DAT
C
      WRITE(8,711) NCLF,RMFA75,RMFA,PHIR,VSH,DTMA,PHSN,
     *           SWU,SXOU,ROHY,SWIR
711   FORMAT(1X,F8.0,4(F6.3,1X),(F6.1,1X),5(F6.3,1X)/)
C
C       Analysis File
C
      WRITE(9,755) DPTH,RHOB,CNLS,DLT,RT,RXO,GR,VSH,ROHY,SXO,PHIE,SW
755   FORMAT(1X,(F7.1,1X),(F7.3,1X),(F5.3,1X),(F5.1,1X),2(F6.1,1X),
     *      (F5.1,1X),5(F5.3,1X))
C
```

APPENDIX TWO



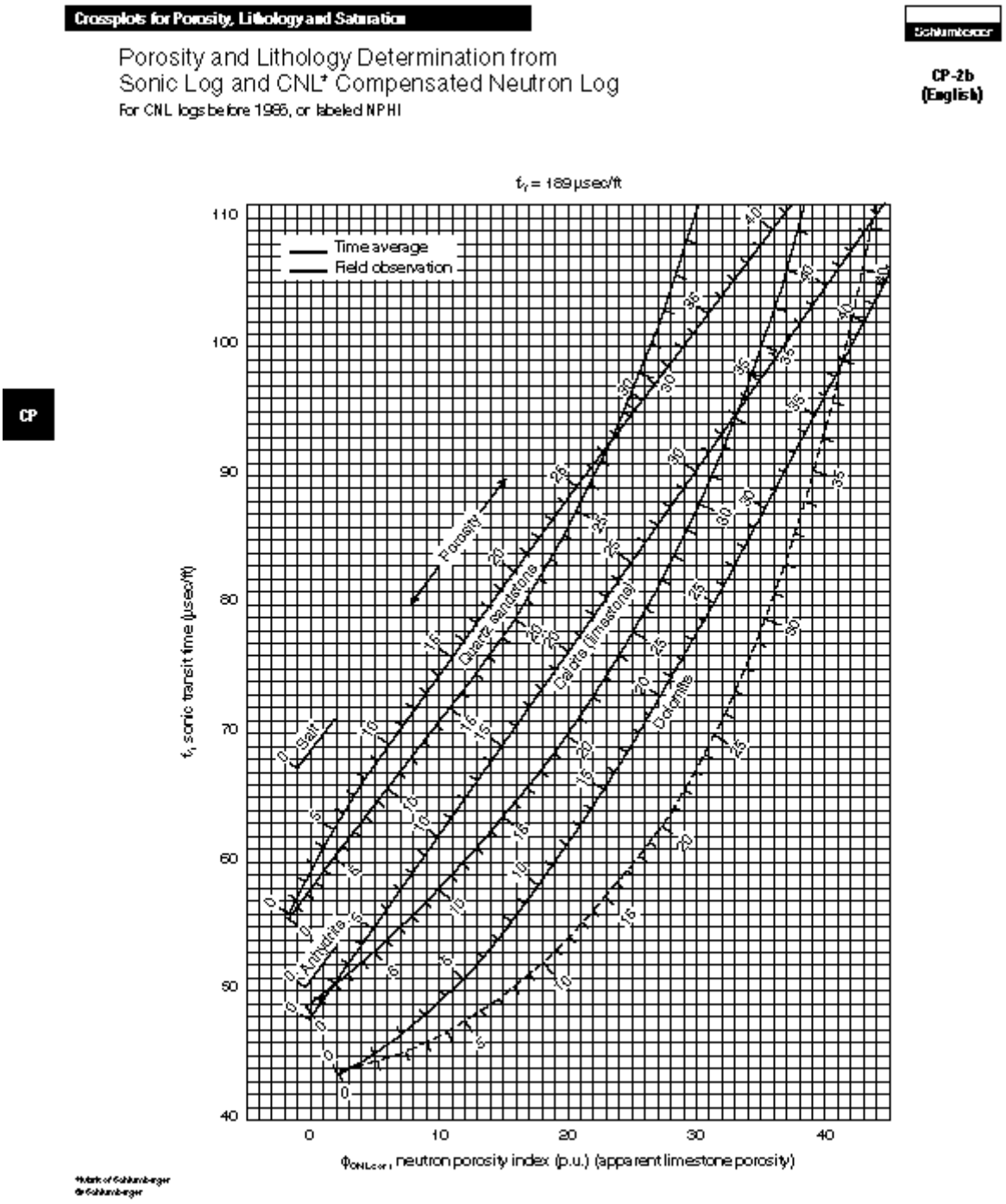
Flow Chart One

APPENDIX THREE

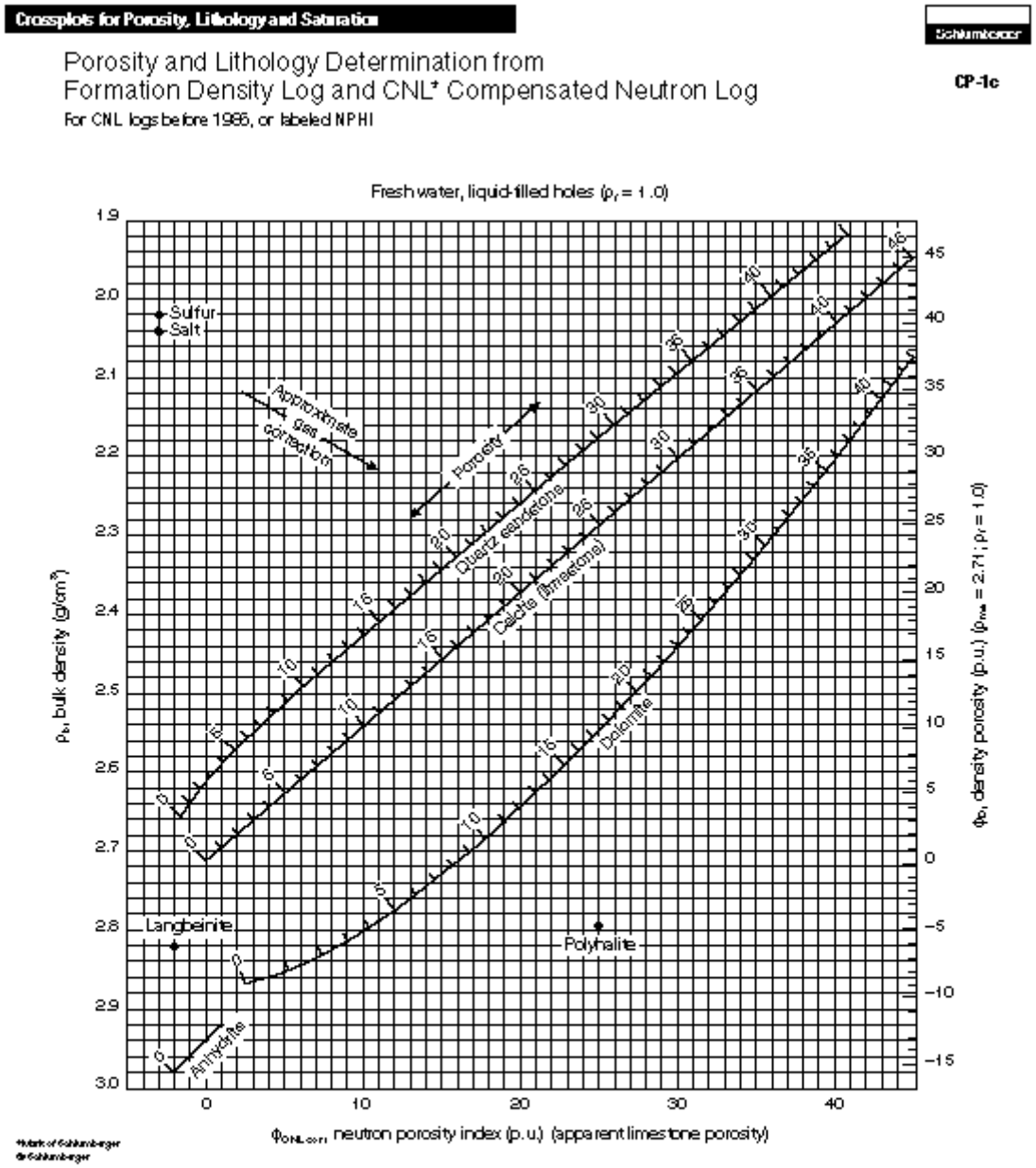


Flow Chart Two

APPENDIX FOUR



APPENDIX FIVE



NOMENCLATURE

Symbol	Description	Units
R_w	Formation water resistivity at formation temperature	Ohm-M
R_{weq}	Equivalent formation water resistivity at formation temperature	Ohm-M
FT	Formation temperature DegF (or DegC if specified)	°F
SSP	Static Spontaneous Potential	mv
SP	Spontaneous Potential Log	mv
R_t	True Formation Resistivity Un-invaded Zone	Ohm-M
R_{xo}	Formation Resistivity Flushed Zone	Ohm-M
R_m	Resistivity of the mud at formation temperature	Ohm-M
GRI	Gamma Ray Index	v/v
GR	Gamma Ray Log	API
$GRsh$	Gamma Ray response in 100% shale	API
$GRcl$	Gamma Ray response in clean formation	API
Vsh	Volume of shale	v/v
Vsh_{ND}	Volume of shale from Neutron -x- Density	v/v
Φ_N	Porosity from Neutron	v/v
Φ_D	Porosity from Density	v/v
Φ_{Nsh}	Neutron porosity response in 100% shale	v/v
Φ_{Dsh}	Density porosity response in 100% shale	v/v
Φ_{Ncl}	Neutron porosity response in clean formation	v/v
Φ_R	Porosity from True Resistivity	v/v
A	Formation Factor Coefficient	
M	Cementation Exponent	
ρ_{ma}	Matrix Density	gm/cc
ρ_{fl}	Fluid Density	gm/cc
Φ_S	Porosity from Sonic	v/v
ΔT_{ma}	Matrix travel time	us/ft
K_{HR}	Constant in Hunt-Raymer sonic porosity equation	
ΔT	Sonic log, travel time	us/ft
Φ_{NS}	Porosity from Neutron -x- Sonic cross plot	v/v
Φ_{ND}	Porosity from Neutron -x- Density cross plot	v/v
Φ_T	Total Porosity	v/v
Φ	Effective Porosity	v/v
V_{sh}	Volume of shale	v/v
$\Delta\Phi_{N\ Excvtn}$	Neutron porosity excavation effect correction	v/v
S_{wh}	Hydrogen Index of the saturating fluid	v/v
ρ_{hyd}	In-situ hydrocarbon density	gm/cc
ρ_{mf}	In-situ mud filtrate density	gm/cc
P	ppm NaCl of formation water divided by 10^6	ppm/1E6

$\Delta\Phi_{N\ Hyd}$	Neutron porosity hydrocarbon correction	v/v
S_{xo}	Flushed zone water saturation	v/v
Γ	Tool dependent constant in Neutron correction	
$\Delta\rho_{Hyd}$	Density porosity hydrocarbon correction	v/v
Ω	Tool dependent constant in Density correction equation	
S_w	Water Saturation	v/v
N	Saturation exponent	
R_{sh}	Resistivity of 100% shale	Ohm-M
S_{wt}	Total Water Saturation	v/v
S_{wb}	Bound Water Saturation	v/v
C_t	True Formation Conductivity	mmho/m
C_{wf}	Conductivity of free water	mmho/m
C_{wb}	Conductivity of bound water	mmho/m
Φ_{Tsh}	Total porosity of 100% shale	v/v
B	Equivalent counter-ion conductance	mho-m/meq/cm^3
Q_v	Cationic exchange capacity per unit pore volume	meq/cm^3
M^*	Cementation exponent free of shaliness effects in Waxman-Smits equation	
F^*	Formation factor free of shaliness effects in Waxman-Smits equation	
R_{wf}	Resistivity of free formation water at formation temperature	Ohm-M
Q_{Vn}	Cationic exchange capacity of 100% shale	mho-m/meq/cm^3
R_{wb}	Resistivity of bound water at formation temperature	Ohm-M
θ	Ratio of Neutron to Density porosity	v/v
β	Constant in in-situ hydrocarbon density equation	
CEC	Cationic Exchange Capacity	meq/gm
V_{disp}	Dispersed Shale fraction of Vsh	
V_{struc}	Structural Shale fraction of Vsh	
V_{lam}	Laminated Shale fraction of Vsh	
S_{HT}	Total Hydrocarbon Saturation conventional Sandwich Model	
$S_{HT\ sd}$	Total Hydrocarbon Saturation in the laminated sand sequence Sandwich Model	

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