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RW

(A TWO PASS METHOD OF WIRELINE LOG
INTERPRETATION FOR HYDROCARBON
RESERVOIR EVALUATION;
COMPUTER PROGRAM RW)

by

G.R. MORRISON

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I Introduction

The most time consuming phase of wireline log interpretation for hydrocarbon reservoir evaluation is the determination of the following formation and drilling parameters:

(1) water resistivity and salinity

(2) mud filtrate resistivity at formation temperature and mud filtrate salinity

(3) shale properties

- gamma ray value
- spontaneous potential baseline value
- apparent porosity
- density
- sonic transit time
- resistivity

(4) clean matrix properties

- gamma ray value
- spontaneous potential value
- density
- sonic transit time.

The purpose of computer program RW is to calculate these parameters required for log interpretation using the information supplied on a complete suite of digitised wireline logs. Calculation of these parameters constitutes the "first pass" required to interpret the logs. The "second pass" is the calculation of the volume of shale, effective porosity and water saturation. BMR has two computer programs to accomplish the second pass. These programs are LOG4 and DW (detailed in BMR records 1978/3 and 1984/8 respectively).

Figure 1 shows how these three computer programs fit into the overall wireline log interpretation process. Program RW has been developed over a period of 15 months since April 1983 so that it could operate under a wide variety of field conditions. The program itself is written in Fortran 77 language and requires a computer terminal that provides a paper copy of the results that are generated. This requirement enables the program to be user interactive.

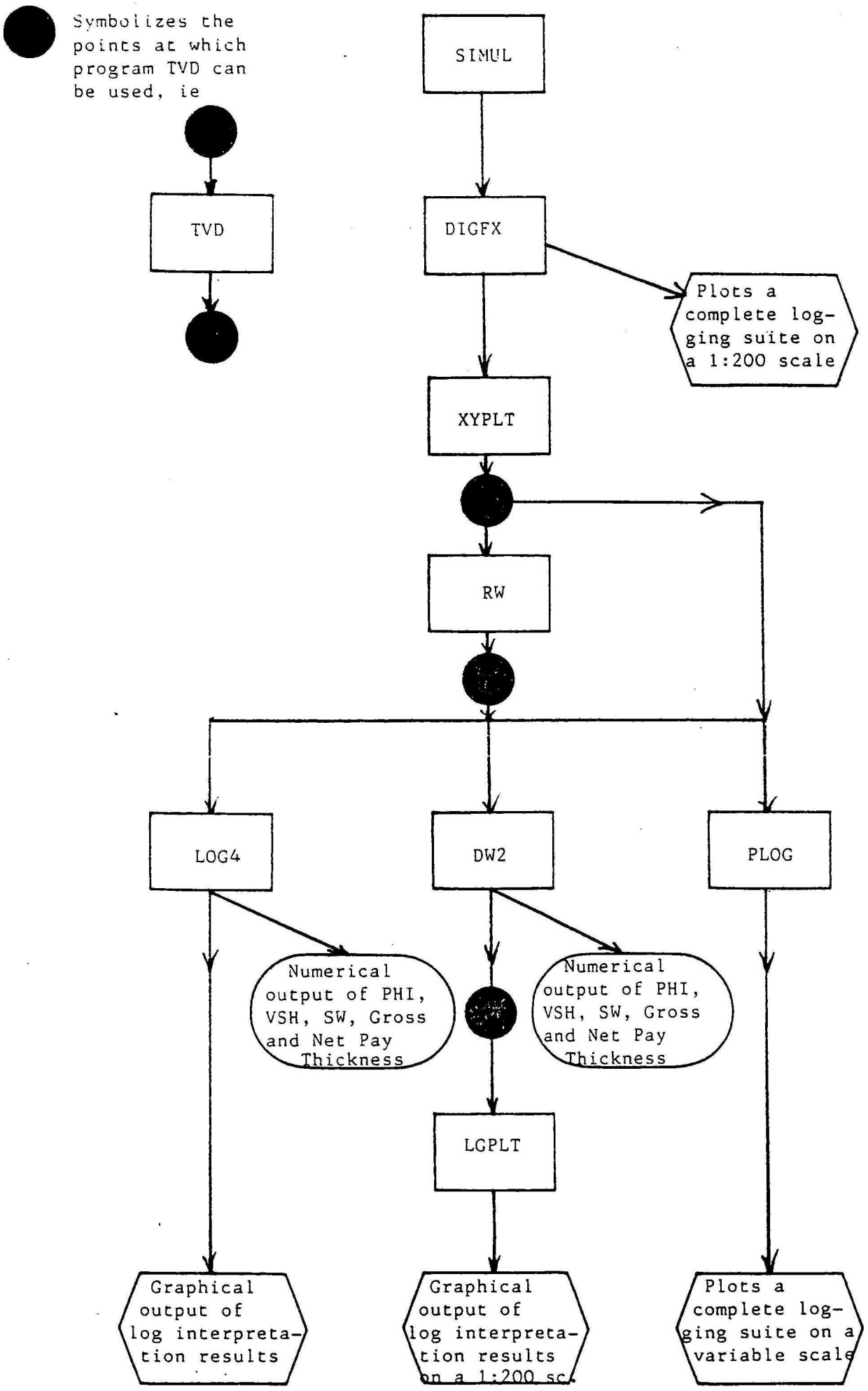


Figure 1 - Flowchart of all the Computer Programs Currently used for Wireline Log Analyses. Definitions of each of the computer programs shown on this figure are given in Appendix 1.

II OPERATING INSTRUCTIONS FOR THE PROGRAM

An example of compiling and loading computer program RW is shown on page 5. A sample program run is shown on pages 6 to 12.

The program run can be divided into five parts, each part is discussed below:

Part (1) (refer pages 6 to 7) asks a series of questions to ascertain the following information:

(a) program run number and date

(b) the type of wireline logs that are present

(c) if a plot is required from the second pass of the log interpretation (eg computer programs LOG4 and DW)

(d) whether metric or imperial measurement units are used

(e) the resistivity of the mud filtrate and the temperature at which this resistivity was calculated. Also the formation temperature so that the resistivity of the mud filtrate can be converted to reservoir conditions

(f) the hydrocarbon density at reservoir conditions

(g) the borehole diameter

(h) the Archie coefficient used for determining the water resistivity by the Archie equation.

Part (2) (refer pages 7 to 9) - The primary aim of this section is to print out the value of crossplotted porosity and matrix density as well as water resistivity and salinity against depth. Other results which are printed out against depth are the gamma ray log values and crossplotted matrix transit time computed from the sonic, neutron and density logs. Also, the deep resistivity log can be compared with the true formation resistivity computed within program RW from algorithms which simulate butterfly charts used for correcting the resistivity logs for the borehole environment.

Part (3) (refer page 10) - In this section the log interpretation parameters relating to the formation water, mud filtrate, the 100% shale zone and the reservoir sand are printed out. These are the results which were computed within program RW by selecting the values representative of these parameters calculated in part (2) of the program run.

Part (4) (refer page 11) - Here a frequency plot of the pre-crossplotted neutron-density log data is generated. This plot is primarily used for the selection of the density and apparent porosity of the shale zone, providing a 100% shale zone exists within the digitised data file. The plot can also be used for observing the effects of shale and light hydrocarbons on the reservoir sand log data.

Part (5) (refer page 12) - If the program user is not satisfied with the log interpretation parameters selected by program RW, then it is possible to override them in this part of the program. Very often program RW selects erroneous parameters due to the presence of radioactive material or the absence of a 100% shale zone in the digitised data file. After all changes have been made, program RW writes the parameters to the top six lines of the data file in a format which is compatible with computer programs LOG4, DW and PLOG (Figure 1). When this has been accomplished the computer will reply with the cursor (!), (refer page 12).

A comparison of the data file before and after being processed by program RW is shown on pages 13 and 14 respectively. The data file (page 14) is now in a format which enables the "second pass" of the log interpretation (programs LOG4 and DW).

NOTE: R. De Nardi, author of program 'PLOG' (Figure 1) has a record in preparation on this computer program. The object of PLOG is to plot digitised wireline log data on a variable scale for the purposes of correlating log character across a field.

(i) A Sample Program Compilation and Loading

```
FT,3RW,,%RW
$END FTN7X:  No disasters,  No errors,  No warnings.
!
```

compile the program

```
RU,LOADR
/LOADR:   EB
/LOADR:   REL,%RW
/LOADR:   EN
  /LOADR:RW     READY AT 11:37 AM  THU.,  5  JULY, 1984
  /LOADR:$END
!
```

load the program

- The underlined type represents user input

(ii) A Sample Program Run

Part (1) - The underlined type represents user input

```
RU,RW

    INPUT FILE NAME  (I.E.  name:SC:CRT)
WELLXY:919:9

    ENTER RUN NUMBER (E.G. 0001) FOUR DIGITS AND DATE (E.G. 21-10-78)
000109-08-84

    FOR THE FOLLOWING SWITCHES ENTER THE NUMBER CORRESPONDING TO THE STATEMENT

    IPORF:
    1= FINAL POROSITY IS FROM NEUTRON DENSITY CROSSPLOT
    2= FINAL POROSITY IS AVERAGE OF SONIC PLUS NEUTRON DENSITY CROSSPLOT
    3= FINAL POROSITY IS AVERAGE OF SIMPLEX PLUS SONIC PLUS NEUTRON DENSITY CROSSPLOT
1

    IHYDR= HYDROCARBON DETECTION SWITCH (I.E. IS Rxo LOG PRESENT ?)
    1= YES , 0= NO
1

    IPL= PLOT SWITCH (1= YES , 0= NO)
1

    IRM= RESISTIVITY CORRECTION IN ORDER TO APPLY CORRECT BUTTERFLY CHART CORRECTION FOR Rt
    1= LL8, ILM, ILD;  2= Rxo, LLs, LLd;
    0= NO Rm LOG OR SOME OTHER RESISTIVITY COMBINATION IS PRESENT
2

    MDPH= METRIC DEPTH (1= METRES; 0= FEET)
1

    MTAC= METRIC INTERVAL TRANSIT TIME
    1= MICROSECONDS/METRE; 0= MICROSECONDS/FOOT
1

    MTEM= METRIC TEMPERATURE (1= CENTIGRADE; 2= FAHRENHEIT)
1

    LUN= INTERMEDIATE CALCULATIONS PRINT-OUT (DEBUG)
    6= YES; 11= NO , NO OTHER VALUES ARE PERMITTED
11

    NLTYPE= TYPE OF NEUTRON LOG (1= SNP; 2= CNL; 3= API UNITS (E.G. GNT TOOL))
2
```

ISP= IS SP RELIABLE; 1= YES, 0= NO

0

ENTER THE RESISTIVITY OF THE MUD FILTRATE AND THE TEMPERATURE AT WHICH IT WAS EVALUATED
(SEPARATE BY A COMMA)

0.104,28.0

ENTER THE FORMATION TEMPERATURE

75.0

ENTER THE NEUTRON LOG CORRECTION FOR THE BOREHOLE ENVIRONMENT
(REFERENCE CHARTS Por-14b AND Por-14bm OF THE LOG INTERPRETATION CHART BOOK, 1979 EDITION)

0.01

ENTER THE HYDROCARBON DENSITY (G/CC)

0.7

ENTER THE BOREHOLE DIAMETER (INCHES)

12.25

ENTER THE ARCHIE COEFFICIENT

0.81

DEPTH	GAMMA	PHI	RHOma	TTma	Rdeep	Rt	Rw(ARCHIE)---->	SALINITY	Rw(RATIO)---->	SALINITY
1025.0	112.5	.291	2.887	0.00	1.0	1.1	.115	25633.2	.059	54761.1
1025.5	111.6	.285	2.808	0.00	1.1	1.2	.122	24076.4	.072	43456.1
1026.0	108.4	.292	2.761	0.00	1.1	1.2	.127	22883.8	.065	49037.9
1026.5	114.7	.279	2.727	0.00	1.1	1.2	.116	25342.9	.059	54761.1
1027.1	111.7	.264	2.733	0.00	1.2	1.3	.113	25964.5	.054	60133.6
1027.6	112.8	.258	2.783	0.00	1.3	1.4	.118	24888.5	.076	40508.7
1028.1	97.9	.250	2.906	0.00	1.4	2.6	.202	13853.7	.127	23010.4
1028.6	95.3	.227	2.902	0.00	1.7	1.9	.119	24537.4	.062	51041.5
1029.1	93.5	.213	2.920	0.00	1.7	1.8	.103	28838.4	.045	75735.5
1029.6	98.4	.253	2.918	0.00	1.7	1.9	.148	19428.3	.067	47381.5
1030.1	96.2	.218	2.961	0.00	1.9	2.1	.123	23777.7	.086	35485.3
1030.6	83.7	.142	2.985	0.00	2.3	2.5	.062	51119.3	.050	66738.1
1031.1	82.7	.163	3.045	0.00	2.0	2.2	.072	42981.9	.054	60897.0
1031.6	84.1	.146	3.003	0.00	2.5	2.8	.073	42679.0	.039	89145.7
1032.2	84.1	.146	3.015	0.00	2.3	2.5	.066	47918.4	.052	63819.9
1032.7	85.7	.208	3.127	0.00	1.3	1.4	.076	40666.5	.035	103278.1
1033.2	77.1	.157	3.146	0.00	1.2	1.3	.041	84792.6	.040	87255.4
1033.7	78.7	.186	3.041	0.00	1.2	1.2	.051	64565.1	.064	49509.4
1034.2	86.5	.153	3.126	0.00	.9	.9	.026	149608.4	.060	53348.9
1034.7	88.7	.243	3.160	0.00	.8	.9	.064	49421.8	.117	25019.9
1035.2	91.8	.287	3.026	0.00	1.0	1.1	.109	27146.8	.057	56555.1
1035.7	102.3	.274	2.952	0.00	1.0	1.1	.102	29202.6	.065	48473.3

Part (1) (Continued)

Part (2)

Part (2)
(Continued)

1037.8	88.0	.169	2.848	0.00	2.2	2.4	.086	35608.7	.059	54761.1
1038.3	72.7	.111	2.977	0.00	4.0	4.4	.067	47072.0	.065	48473.3
1038.8	66.1	.115	2.903	0.00	3.8	4.2	.068	45902.6	.062	51430.2
1039.3	70.9	.157	2.897	0.00	1.6	1.8	.053	61247.2	.055	58779.1
1039.8	97.9	.270	2.930	0.00	1.0	1.1	.099	30141.6	.045	74681.4
1040.3	107.2	.168	3.071	0.00	.9	1.0	.035	103194.2	.059	54761.1
1040.8	114.5	.182	3.076	0.00	.9	1.0	.040	85549.3	.059	54761.1
1041.3	121.2	.190	3.105	0.00	1.6	1.6	.071	43918.3	.071	43869.9
1041.8	106.7	.166	3.117	0.00	1.9	2.1	.071	43639.3	.043	78542.9
1042.4	111.4	.153	3.056	0.00	1.8	1.8	.052	63416.4	.056	57253.2
1042.9	123.3	.199	2.959	0.00	1.7	1.9	.092	32944.0	.071	43780.6
1043.4	113.6	.222	2.960	0.00	1.4	1.5	.094	32101.5	.082	37248.4
1043.9	108.9	.193	2.977	0.00	1.6	1.7	.080	38318.6	.046	72230.4
1044.4	113.6	.220	2.988	0.00	1.3	1.4	.086	35531.3	.059	54761.1
1044.9	114.2	.247	2.939	0.00	1.5	2.8	.212	13153.7	.125	23376.8
1045.4	96.0	.225	2.849	0.00	1.8	2.0	.124	23601.4	.088	34464.0
1045.9	75.2	.254	2.710	0.00	2.4	2.6	.211	13225.1	.141	20476.2
1046.4	73.9	.242	2.540	0.00	3.1	4.0	.288	9451.2	.235	11726.7
1046.9	82.8	.223	2.625	0.00	2.0	2.2	.136	21332.7	.098	30629.9
1047.5	92.4	.247	2.775	0.00	2.2	2.4	.182	15520.7	.076	40717.8
1048.0	118.0	.247	2.778	0.00	2.4	2.6	.199	14073.9	.117	25019.9
1048.5	83.6	.309	2.665	0.00	2.4	3.1	.370	7236.5	.239	11564.0
1049.0	68.0	.304	2.680	0.00	2.1	3.1	.353	7590.3	.183	15363.0
1049.5	68.0	.276	2.697	0.00	1.7	2.7	.252	10898.3	.130	22436.8

DEPTH	GAMMA	PHI	RHOma	TTma	Rdeep	Rt	Rw(ARCHIE)---->	SALINITY	Rw(RATIO)---->	SALINITY
1050.0	73.7	.227	2.735	0.00	1.7	1.7	.108	27417.7	.070	44854.7
1050.5	79.3	.221	2.737	0.00	1.7	1.7	.102	29188.1	.076	40942.0
1051.0	85.5	.221	2.716	0.00	1.7	3.0	.184	15314.1	.148	19421.0
1051.5	98.7	.306	2.669	0.00	1.4	1.9	.218	12732.9	.144	19958.8
1052.0	94.9	.302	2.713	0.00	1.7	2.6	.291	9354.2	.153	18676.7
1052.6	76.5	.302	2.663	0.00	1.5	2.1	.236	11704.0	.160	17859.9
1053.1	70.5	.309	2.636	0.00	1.1	1.7	.203	13737.1	.131	22099.1
1053.6	75.8	.303	2.649	0.00	1.0	1.8	.206	13534.5	.139	20799.7
1054.1	87.9	.286	2.674	0.00	.9	.9	.091	33226.6	.060	53348.9
1054.6	76.9	.292	2.678	0.00	.8	1.4	.150	19061.9	.152	18842.7
1055.1	73.5	.309	2.681	0.00	.7	1.0	.115	25521.2	.131	22233.6
1055.6	79.7	.304	2.662	0.00	.7	.7	.080	38317.8	.062	51147.1
1056.1	83.2	.289	2.649	0.00	.7	1.1	.115	25581.1	.119	24543.8
1056.6	88.0	.295	2.685	0.00	.8	1.3	.139	20810.1	.115	25652.8
1057.1	95.6	.248	2.724	0.00	1.1	1.2	.094	31943.5	.047	70699.2
1057.7	105.0	.292	2.751	0.00	.8	.9	.092	32984.4	.058	55495.0
1058.2	67.5	.251	2.764	0.00	.7	.7	.055	59638.5	.062	51147.1
1058.7	70.8	.235	2.756	0.00	.7	.7	.048	69640.0	.062	51147.1
1059.2	115.3	.292	2.676	0.00	.7	1.1	.118	24926.4	.119	24543.8
1059[illegible]	122.3	[illegible]293	2.641	0.00	.7	[illegible]8	.08[illegible]	37[illegible]66.9	[illegible]68	[illegible]5831.1

Part (2)
(Continued)

1060.7	80.0	.301	2.668	0.00	.6	.6	.067	46867.6	.064	49509.4
1061.2	75.6	.305	2.645	0.00	.6	.7	.076	40717.3	.070	44376.7
1061.7	73.9	.315	2.659	0.00	.6	.6	.074	42157.2	.064	49509.4
1062.2	81.5	.319	2.658	0.00	.6	.6	.075	41097.7	.064	49509.4
1062.8	87.3	.319	2.668	0.00	.6	.6	.075	41111.4	.064	49509.4
1063.3	98.9	.314	2.635	0.00	.6	.7	.080	38221.1	.070	44376.7
1063.8	122.3	.322	2.774	0.00	1.9	2.1	.267	10240.0	.034	106719.3
1064.3	146.9	.309	2.843	0.00	1.8	2.0	.234	11814.8	.046	73150.1
1064.8	149.0	.314	2.846	0.00	1.9	2.9	.347	7749.9	.109	27206.0
1065.3	139.5	.326	2.992	0.00	1.3	1.4	.187	15003.2	.045	75213.8
1065.8	108.0	.243	2.817	0.00	.8	.9	.064	49177.0	.067	46928.2
1066.3	67.7	.171	2.894	0.00	.9	1.0	.036	99957.9	.059	54761.1
1066.8	57.7	.185	2.798	0.00	.8	.9	.037	94472.9	.059	54761.1
1067.3	52.5	.230	2.699	0.00	.8	.9	.057	56082.3	.059	54761.1
1067.9	52.6	.246	2.710	0.00	.9	1.0	.074	42033.0	.059	54761.1
1068.4	49.7	.220	2.680	0.00	.8	.9	.053	61967.2	.067	46928.2
1068.9	53.6	.218	2.738	0.00	.8	.9	.052	63338.0	.067	46928.2
1069.4	50.3	.193	2.708	0.00	.9	1.0	.045	74119.1	.059	54761.1
1069.9	48.2	.218	2.690	0.00	.9	1.0	.057	56782.7	.047	71073.0
1070.4	55.2	.211	2.697	0.00	.9	1.0	.053	61279.9	.057	56079.1
1070.9	54.3	.208	2.655	0.00	.9	1.0	.052	63610.2	.057	56079.1
1071.4	44.1	.220	2.656	0.00	.9	1.0	.059	54410.9	.053	61951.6
1071.9	47.9	.197	2.671	0.00	.9	1.0	.048	70037.9	.048	69361.3
1072.5	53.9	.208	2.681	0.00	.9	1.0	.055	58696.7	.062	51716.6
1073.0	60.2	.227	2.714	0.00	.9	1.0	.063	50264.2	.059	54761.1
1073.5	51.6	.200	2.683	0.00	1.0	1.1	.054	60188.6	.053	61222.8
1074.0	47.1	.222	2.694	0.00	1.0	1.0	.061	52281.0	.059	54124.5
1074.5	54.8	.232	2.650	0.00	.8	.9	.058	55130.3	.059	54761.1
1075.0	59.2	.237	2.672	0.00	.9	1.0	.069	45730.6	.059	54761.1

Part (3)

FORMATION WATER PROPERTIES

CLEANEST POINT USING THE ARCHIE EQUATION:
(1) Rw= .0590 OHM-M
DEPTH= 1071.4 METRES
FORMATION TEMPERATURE= 75.0 DEGREES CENTIGRADE
WATER SALINITY= 54410.9 PPM.

MUD FILTRATE PROPERTIES

Rmf= .0533 OHM-M AT FORMATION TEMPERATURE
MUD FILTRATE SALINITY= 61222.8 PPM.

SHALE PROPERTIES

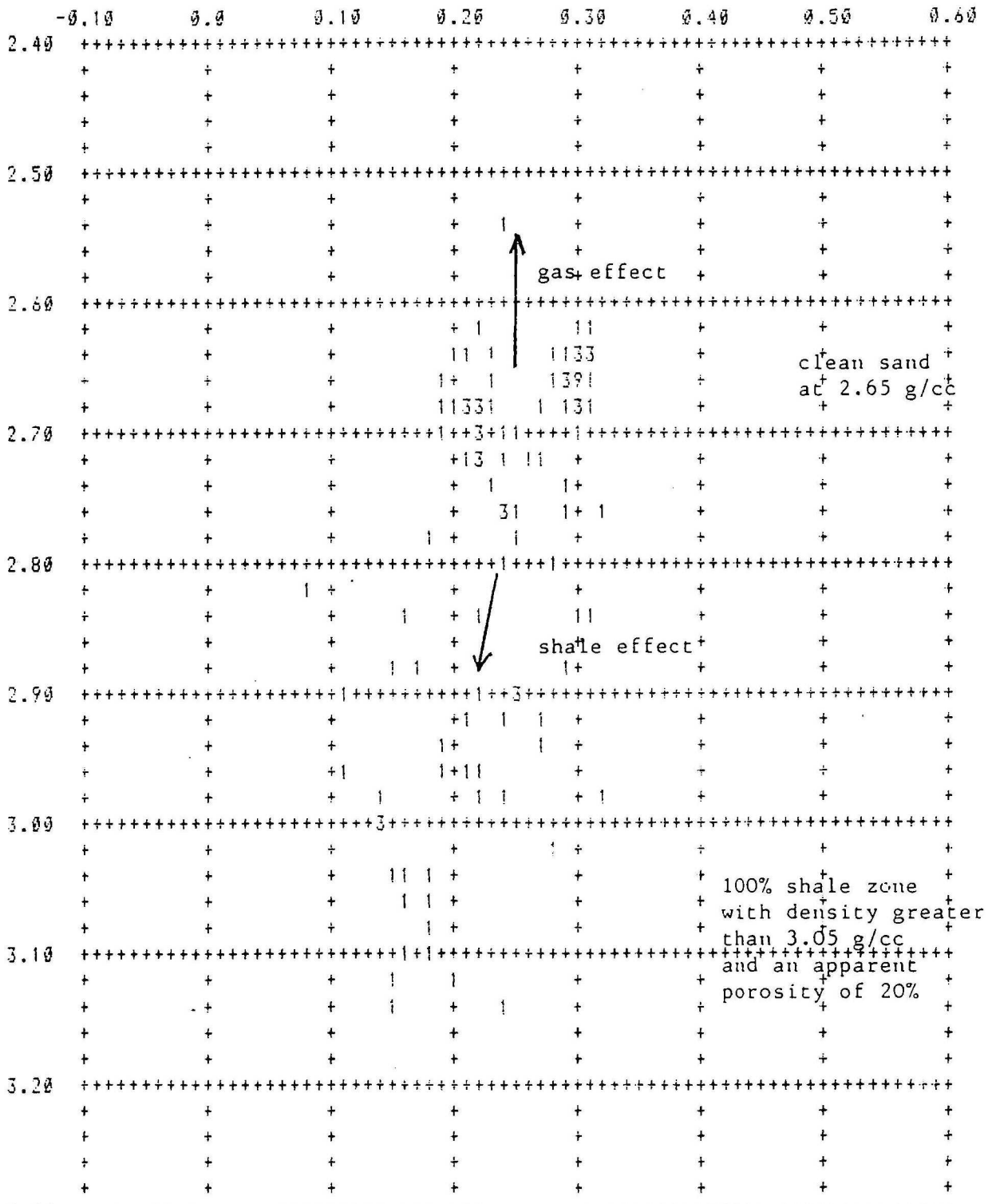
SHALIEST POINT AT A DEPTH OF 1033.2 METRES
(2) GAMMA RAY VALUE= 149.0 API UNITS
(3) SP BASE LINE VALUE= 0.0 mV
(4) NEUTRON LOG POROSITY= .180
(5) DENSITY LOG VALUE= 3.137 G/CC
(6) SHALE TRANSIT TIME= 0.00 uS/metre.
(7) SHALE RESISTIVITY= 1.31 OHM-M

MATRIX PROPERTIES
---

(8) GAMMA RAY VALUE= 44.1 API UNITS
(9) SP= 0.0 mV
(10) APPARENT MATRIX DENSITY= 2.695 G/CC
(11) APPARENT MATRIX TRANSIT TIME= 0.00 uS/metre.

PART (4)

CROSSPLOTTED POROSITY (PHI) VERSUS MATRIX DENSITY (RHOma)



Part (5)

The underlined type represents user input

```
DO YOU WANT TO CHANGE ANYTHING ?
TO ALTER A VARIABLE TYPE IN THE BRACKETED NUMBER
FOR NO CHANGE TYPE IN Ø (=ZERO)
1
ENTER NEW Rw
Ø.Ø85

DO YOU WANT TO CHANGE ANYTHING ?
TO ALTER A VARIABLE TYPE IN THE BRACKETED NUMBER
FOR NO CHANGE TYPE IN Ø (=ZERO)
1Ø
ENTER NEW MATRIX DENSITY
2.65

DO YOU WANT TO CHANGE ANYTHING ?
TO ALTER A VARIABLE TYPE IN THE BRACKETED NUMBER
FOR NO CHANGE TYPE IN Ø (=ZERO)
Ø
!
```

The computer replies with the cursor when the information calculated by RW is entered into the data file

(iii) A Sample Data File Before Being Processed by PROGRAM RW

```
WELL A1 (1025m TO 1075m) WELLXY
1025.0,112.5,2.338,.354,  0.0,  0.0,   1.0,   1.0,   1.0
1025.5,111.6,2.292,.316,  0.0,  0.0,    .9,   1.0,   1.1
1026.0,108.4,2.247,.303,  0.0,  0.0,   1.0,   1.0,   1.1
1026.5,114.7,2.246,.276,  0.0,  0.0,   1.1,   1.1,   1.1
1027.1,111.7,2.276,.264,  0.0,  0.0,   1.3,   1.2,   1.2
1027.6,112.8,2.322,.280,  0.0,  0.0,   1.0,   1.2,   1.3
1028.1, 97.9,2.429,.326,  0.0,  0.0,   1.1,   1.2,   1.4
1028.6, 95.3,2.469,.304,  0.0,  0.0,   1.6,   1.6,   1.7
1029.1, 93.5,2.511,.300,  0.0,  0.0,   2.2,   1.5,   1.7
1029.6, 98.4,2.433,.334,  0.0,  0.0,   1.5,   1.6,   1.7
1030.1, 96.2,2.533,.323,  0.0,  0.0,   1.3,   1.8,   1.9
1030.6, 83.7,2.704,.270,  0.0,  0.0,   2.7,   2.0,   2.3
1031.1, 82.7,2.712,.317,  0.0,  0.0,   2.2,   1.7,   2.0
1031.6, 84.1,2.711,.282,  0.0,  0.0,   3.8,   2.1,   2.5
  :       :     :     :     :     :     :     :     :
  :       :     :     :     :     :     :     :     :
1073.0, 60.2,2.324,.219,  0.0,  0.0,    .9,    .9,    .9
1073.5, 51.6,2.347,.177,  0.0,  0.0,   1.1,   1.0,   1.0
1074.0, 47.1,2.317,.205,  0.0,  0.0,    .9,    .8,   1.0
1074.5, 54.8,2.268,.195,  0.0,  0.0,    .8,    .8,    .8
```

```
 WELL A1 (1025m TO 1075m) WELLXY
)00109-08-84                                          1 sample of the type of
 1,1,1,2,1,1,1,11,2,6,0                               2 information calculated
  98, 75.0, .061, .053,1.0,620.0, 0.000               3 by RW, placed in the
  44.1,2.650,  0.0,  0.0                              4 top six lines
 149.0, 1.2,3.130,  0.0, .220,  0.0                   5 of the data file.
  .067, .700,12.250                                   6
 1025.0,112.5,2.338,.354,  0.0,  0.0,   1.0,   1.0,   1.0
 1025.5,111.6,2.292,.316,  0.0,  0.0,    .9,   1.0,   1.1
 1026.0,108.4,2.247,.303,  0.0,  0.0,   1.0,   1.0,   1.1
 1026.5,114.7,2.246,.276,  0.0,  0.0,   1.1,   1.1,   1.1
 1027.1,111.7,2.276,.264,  0.0,  0.0,   1.3,   1.2,   1.2
 1027.6,112.8,2.322,.280,  0.0,  0.0,   1.0,   1.2,   1.3
 1028.1, 97.9,2.429,.326,  0.0,  0.0,   1.1,   1.2,   1.4
 1028.6, 95.3,2.469,.304,  0.0,  0.0,   1.6,   1.6,   1.7
 1029.1, 93.5,2.511,.300,  0.0,  0.0,   2.2,   1.5,   1.7
 1029.6, 98.4,2.433,.334,  0.0,  0.0,   1.5,   1.6,   1.7
 1030.1, 96.2,2.533,.323,  0.0,  0.0,   1.3,   1.8,   1.9
 1030.6, 83.7,2.704,.270,  0.0,  0.0,   2.7,   2.0,   2.3
 1031.1, 82.7,2.712,.317,  0.0,  0.0,   2.2,   1.7,   2.0
 1031.6, 84.1,2.711,.282,  0.0,  0.0,   3.8,   2.1,   2.5
  :       :     :     :     :     :      :     :     :
  :       :     :     :     :     :      :     :

 1073.0, 60.2,2.324,.219,  0.0,  0.0,    .9,    .9,    .9
 1073.5, 51.6,2.347,.177,  0.0,  0.0,   1.1,   1.0,   1.0
 1074.0, 47.1,2.317,.205,  0.0,  0.0,    .9,    .8,   1.0
 1074.5, 54.8,2.268,.195,  0.0,  0.0,    .8,    .8,    .8
 1075.0, 59.2,2.276,.210,  0.0,  0.0,    .9,    .9,    .9
-1
```

III EQUATIONS USED IN THE PROGRAM

Note: All formulae are care of Schlumberger except where specified.

(i) Adjusting the Resistivity of the Mud Filtrate to Resistivity at Reservoir Conditions

The equations used for this conversion are:

case (a) if the temperature is in degrees centigrade

$$Rmf_r = Rmf_s\ (T_s + 21.5)/(T_r + 21.5)$$

case (b) if the temperature is in degrees fahrenheit

$$Rmf_r = Rmf_s\ (T_s + 6.66)/(T_r + 6.77)$$

where Rmf = resistivity of the mud filtrate

T = temperature

r subscript = reservoir conditions

s subscript = surface conditions

(ii) Total Porosity Øt and Matrix Density ρma

The program RW computes total porosity and matrix density from the neutron-density logging tool combination. The equations used for this calculation are:

(Note: the charts referred to here are from the Schlumberger Log Interpretation Chart Book, 1979 Edition)

$$\text{Total porosity, } Øt = \frac{Ølog\ corr + Ød}{2} \qquad \text{(Chart CP-1c)}$$

where Ølog corr = Ø neutron log + ΣØ

ΣØ comes from chart Por-14b or Por-14bm which is used to correct the neutron porosity log for the borehole environment

Ød = density log porosity

$$Ød = \frac{2.71 - ρb}{2.71 - ρmf} \qquad \text{(Chart Por-5)}$$

and 2.71 g/cc = the density of the limestone calibration block with water filled pores.

$$\text{Matrix density, } ρma = \frac{ρb - Øt.ρmf}{1 - Øt}$$

The effect of a light hydrocarbon in the pores of the formation on the neutron-density tool combination is to reduce Øt and ρma calculated by the equations above. The effect of shale on the response of the neutron-density tool combination is to increase ρma.

(iii) Sonic Transit Time of the Matrix TTma

Program RW computes the sonic transit time of the matrix (TTma) from the sonic, neutron and density logging tools. The equation used to calculate TTma uses the value of the total porosity Øt determined from the neutron-density logging tool combination (refer II (ii)). The equation used to calculate TTma is:

$$TTma = \frac{TT1 - TTmf.Øt}{1 - Øt}$$

where Øt = total porosity

TTmf = sonic transit time of the mud filtrate

= 620 µs/metre or 189 µs/foot

TT1 = sonic value read directly from the log

TTma = sonic transit time of the matrix.

In the case where the wireline log data file does not contain sonic log data, the value of TTma is set to zero by default.

(iv) True Formation Resistivity Rt

The true formation resistivity is calculated from one of a choice of three resistivity logging tool combinations. These three choices are:

(a) Induction resistivity tool, the spherically focussed log and the latterlog 8 resistivity tool. This combination can be abbreviated as ILd-ILm-LL8 and the program simulates Schlumberger chart Rint-2A (Kurylowicz, 1978);

(b) The dual latterlog - micro-spherically focussed logging tool combination. This combination is abbreviated as LLd-LLs-Rxo and the program simulates Schlumberger chart Rint-9 (Bateman and Konen, 1977);

(c) The dual latterlog resistivity tool without the micro-spherically focussed log can also be used to calculate Rt. This combination is abbreviated as LLd-LLs and simulates the Schlumberger chart Rint-9 in the absence of an Rxo log (Bateman and Konen, 1977).

(v) Formation Water Resistivity, Rw and Salinity

The formation water resistivity is calculated by 2 methods in program RW. These 2 methods are the Archie equation and the ratio method. The equations used are as follows:

(a) Archie Equation (assuming the water saturation = 100%)

$$Rw = Rt \cdot \emptyset t^{m}/a$$

where Øt = total porosity
Rt = true formation resistivity
a = the Archie coefficient
Rw = the water resistivity
m = the cementation factor, set to 2 in RW

The Archie coefficient is read in from the terminal along with the logging switches and drilling parameters in Part (1) of the program run. A general guide for selecting the Archie coefficient without any petrophysical analysis from core samples is to select the coefficient depending on the type of lithology which is believed to be present, ie:

quartz lithology, select a = 0.81
calcite lithology, select a = 1.00
dolomite lithology, select a = 1.20

(b) The ratio method; this method relies on the accuracy of the resistivity ratio: Rmf is to Rxo as Rw is to Rt.

This is expressed mathematically as:

$$\frac{Rw}{Rt} = \frac{Rmf}{Rxo}$$

or $Rw = Rmf.Rt/Rxo$

where Rmf = resistivity of the mud filtrate
Rt = the true formation resistivity
Rxo = resistivity from the micro-spherically focussed log or a mud cake log.

Generally, the ratio method is not very accurate, probably because of the large amounts of relative inaccuracy associated with the resistivity measurements.

The water salinity is also determined for each water resistivity calculation using the formation temperature which was entered at the terminal. The equation used to calculate the water salinity in units of parts per million of sodium chloride is as follows: (R.M. Bateman and C.E. Konen, 1977)

$$\text{salinity} = [(300\ 000)/(R(T+7)-1)]^{1.05}$$

where T = temperature in degrees fahrenheit
R = resistivity from which the salinity is to be calculated.

(vi) Selection of the Cleanest Water Bearing Point

As shown in part (2) of the Sample run, with each value of depth the gamma ray log value and the computed true formation resistivity are printed out. Program RW uses the gamma ray log as a volume of shale indicator. Program RW assumes that the water bearing zone has both a lower gamma ray and resistivity log value than the shale and hydrocarbon bearing zones present in the data file.

The cleanest water bearing point selected by RW is therefore the point at which the product of the gamma ray log value and the true formation resistivity are a minimum. This calculation assumes that the gamma ray log is truly reflective of the shale content of the formation. In practice however, the presence of radioactive material can upset this calculation.

(vii) Selection of the Shaliest Point

The shaliest point in the digitised data file is calculated from the maximum "positive" separation of the neutron and density logging tool readings. This method assumes that the separation of the neutron-density logs is associated with the effect that most shaly formations have on this logging tool combination.

(viii) Averaging of the Clean Water Bearing and 100% Shale Log Interpretation Parameters

The clean (shale) log interpretation parameters are determined by averaging the log or crossplotted log values below (above) a pre-selected cut-off. The present cutoffs are 120% of the cleanest point log values (refer II(vi)) for the clean matrix parameters and 90% of the shaliest point log values (refer II(vii)) for the 100% shale parameters. There is no justification for the selection of these cutoff values other than the fact that they appear to work in the majority of cases.

Therefore, it is advisable where possible when digitising the wireline logs, to include in the digitised interval zones which represent a 100% shale formation and a 100% water bearing clean reservoir sand. Where these zones have not been included, program RW will select erroneous shale and clean matrix parameters. When this fault occurs it can be recognised in part (3) of the program run and overcome at the user input stage in part (5) of the program run.

IV PROGRAM LISTING

The following pages (20 to 33) contain a listing of computer program RW.
Page 34 (Section IV (ii)) contains a flowchart of this computer program.

(i) Program Listing

```
FTN77,Q,L,C
$FILES(0,1)
      PROGRAM RW
C
C       THIS PROGRAM CALCULATES LOG4 AND DW INPUT PARAMETERS FROM A
C       STANDARD DIGITISED LOG DATA FILE FORMAT. THE ONLY INPUT PARAMETER
C       REQUIRING EXTERNAL CALCULATION ARE:
C           - TITLE
C           - RUN AND DATE
C           - SWITCHES AND FLAGS ON LINE 3 OF A STANDARD LOG4 OR DW
C             COMPATIBLE DATA FILE
C           - THE ARCHIE COEFFICIENT
C           - FORMATION TEMPERATURE
C           - DELPOR
C           - HYDROCARBON DENSITY
C           - BOREHOLE DIAMETER
C       ALL OTHER PARAMETERS ARE CALCULATED IN THE PROGRAM
C       AND WILL BE REASONABLE ESTIMATES PROVIDING THE DATA FILE
C       CONTAINS A 100% SHALE AND A 100% WATER ZONE.
C       THE WATER RESISTIVITY IS CALCULATED FROM THE ARCHIE EQUATION
C       AND THE RATIO METHOD.
C       PROGRAM DEVELOPED BY G.R.MORRISON ,JULY 1984.
C       REFERENCE THE SPWLA ARTICLE "THE LOG ANALYST AND THE
C       PROGRAMABLE POCKET CALCULATOR" - BY R.M.BATEMAN AND C.E.KONEN - 1
C       FOR THE ALGORITHM WHICH DETERMINES TRUE FORMATION RESISTIVITY
C       FOR THE DUAL LATTERLOG RESISTIVITY TOOL AND FOR THE EQUATION
C       USED TO DETERMINE WATER SALINITY FROM TRUE FORMATION RESISTIVITY.
C       REFERENCE L.E.KURYLOWICZ FOR THE ALGORITHM WHICH DETERMINES Rt
C       FROM THE INDUCTION RESISTIVITY TOOL.
C       ALL OTHER FORMULAE ARE CARE OF SCHLUMBERGER.
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C       A LISTING OF THE VARIABLES IN THE PROGRAM
C       ------------------------------------------------------------------
C       A= VARIABLE IN RESISTIVITY SECTION
C       ARCHIE= THE ARCHIE COEFFECIENT
C       B= VARIABLE IN THE RESISTIVITY SECTION
C       BB= VARIABLE IN THE RESISTIVITY SECTION
C       BORE= BOREHOLE DIAMETER
C       C= EQUATION IN THE RESISTIVITY SECTION
```

```
C       CC= VARIABLE IN THE RESISTIVITY SECTION
C       CP= 'CLEANEST POINT' ,IS EVALUATED FROM THE SMALLEST VALUE OF
C            THE GAMMA RAY LOG MULTIPLIED BY THE TRUE FORMATION RESISTIVI
C       CPMIN=THE INITIAL VALUE OF CP
C       D= VARIABLE IN THE RESISTIVITY SECTION
C       DELPOR= THE NEUTRON LOG CORRECTION FOR THE BOREHOLE ENVIRONMENT
C       DEN(I)= DENSITY LOG VALUES
C       DENHYD= DENSITY OF THE HYDROCARBON
C       DENMA= DENSITY OF THE MATRIX
C       DENMF= DENSITY OF THE MUD FILTRATE
C       DENSH= DENSITY OF THE SHALE
C       DEPTH(I)= LOG DEPTH VALUES
C       DPHMIN= VALUE OF LOG DEPTH AT WHICH RW IS A MINIMUM
C       FPLT= ARRAY WHICH CONTAINS THE FREQUENCY OF POINTS FROM THE
C              NEUTRON DENSITY CROSSPLOT
C       FPMAX= MAXIMUM NUMBER OCURRING IN FPLT, USED TO NORMALIZE THE FRE
C       GR(I)= GAMMA RAY LOG VALUES
C       GRYMAX= MAXIMUM GAMMA RAY
C       GRYMIN= MINIMUM GAMMA RAY
C       ICP= CLEANEST POINT COUNTER
C       IHYDR= LOG4 SWITCH
C       IPL= LOG4 SWITCH
C       IPORF= LOG4 SWITCH
C       IPRINT= LOG4 SWITCH
C       IRM= LOG4 SWITCH
C       ISHP= SHALIEST POINT COUNTER
C       ISP= LOG4 SWITCH
C       L= LOWER LIMIT FOR AVERAGING MATRIX VALUES
C       LUN= LOG4 SWITCH
C       MDPH= LOG4 SWITCH FOR METRIC OR IMPERIAL DEPTHS
C       MSFL(I)= MICRO SPHERICALLY FOCUSED LOG VALUES
C       MTAC= LOG4 SWITCH FOR METRIC OR IMPERIAL SONIC LOG UNITS
C       MTEM= LOG4 SWITCH FOR METRIC OR IMPERIAL FORMATION TEMPERATURE
C       NAMH2O= NAME OF THE DATA FILE
C       NCP= NUMBER OF CLEAN POINTS
C       NEU(I)= NEUTRON LOG VALUES
C       NLTYPE= LOG4 SWITCH
C       NSHP= NUMBER OF SHALE POINTS
C       NSP= NUMBER OF SAMPLE POINTS IN THE DATA FILE
C       PHID= POROSITY FROM THE DENSITY LOG
C       PHISH= "POROSITY" OF THE SHALE
C       PHIX(I)= CROSSPLOT POROSITY
C       PHSHAV= AVERAGE POROSITY OF THE SHALE
C       PIC= CHARACTER ARRAY WHICH CONTAINS NORMALIZED VALUES FROM FPLT
C       PMF= SALINITY OF THE MUD FILTRATE
C       PORNSH= POROSITY OF THE SHALE
C       Q= QUESTION VARIABLE FOR CHANGING A PARAMETER
C       R= RESISTIVITY IN THE WATER SALINITY SUBROUTINE
C       RHCPAV= AVERAGE DENSITY OF THE CLEANEST POINT
C       RHOCP= DENSITY OF THE CLEANEST POINT
C       RHOMA(I)= APPARENT MATRIX DENSITY
```

```
C       RHOSH= DENSITY OF THE SHALE POINT
C       RHSHAV= AVERAGE DENSITY OF THE SHALE
C       RILD= INDUCTION LOG DEEP RESISTIVITY
C       RILM= INDUCTION LOG MEDIUM RESISTIVITY
C       RLD= RESISTIVITY LOG DEEP
C       RLL8= LATTERLOG 8 RESISTIVITY
C       RLM= RESISTIVITY LOG MEDIUM
C       RMF= RESISTIVITY OF THE MUD FILTRATE
C       RSH= RESISTIVITY OF THE SHALE
C       RSHAV= AVERAGE RESISTIVITY OF THE SHALE
C       RT(I)= TRUE RESISTIVITY OF THE FORMATION
C       RUNDAT= RUN AND DATE
C       RWA= WATER RESISTIVITY
C       RWR= WATER RESISTIVITY CALCULATED FROM THE RATIO METHOD
C       RWMIN= MINIMUM VALUE OF RW
C       SALMF= SALINITY OF THE MUD FILTRATE
C       SALW= SALINITY OF THE FORMATION WATER
C       SALWTR= WATER SALINITY SUBROUTINE
C       SHP= SHALIEST POINT FACTOR
C       SHPMAX= INITIAL VALUE OF THE SHALIEST POINT FACTOR
C       SPMAX= MAXIMUM SP VALUE
C       SPMIN= MINIMUM SP VALUE
C       SP(I)= SP LOG VALUES
C       SSP= SP READING IN A CLEAN MATRIX
C       T=TEMPERATURE IN THE WATER SALINITY SUBROUTINE
C       TACF= SONIC TRANSIT TIME OF THE FORMATION FLUID
C       TACMA= SONIC TRANSIT TIME OF THE MATRIX
C       TACSH= SONIC TRANSIT TIME OF THE SHALE
C       TEM= FORMATION TEMPERATURE
C       TITLE= TITLE OF THE ZONE
C       TT(I)= SONIC TRANSIT TIME LOG VALUES
C       TTCP= SONIC TRANSIT TIME OF THE CLEANEST POINT
C       TTCPAV= THE AVERAGE SONIC TRANSIT TIME OF THE CLEANEST POINT
C       TTF= SONIC TRANSIT TIME OF THE FORMATION FLUID
C       TTMA(I)= APPARENT SONIC TRANSIT TIME OF THE MATRIX
C       TTSH= SONIC TRANSIT TIME OF THE SHALE
C       TTSHAV= AVERAGE SONIC TRANSIT TIME OF THE SHALE
C       U= UPPER LIMIT FOR AVERAGING SHALE VALUES
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      REAL DEPTH(300),GR(300),DEN(300),NEU(300),TT(300),SP(300),
     2MSFL(300),RLS(300),RLD(300),PHIX(300),RHOMA(300),TTMA(300)
     3,RT(300),L
      INTEGER Q,FP,FPLT(81,46)
      CHARACTER*40 TITLE
      CHARACTER*40 RUNDAT
      CHARACTER*1 PIC(81,46)
C      ------------------------------------------------------------------
C      READ IN THE DATA FILE NAME
      CHARACTER *20 NAMH2O
      WRITE(1,5)
5     FORMAT(//,5X,'INPUT FILE NAME  (I.E.  name:SC:CRT)')
```

```
      READ(1,10)NAMH2O
10    FORMAT(A)
      OPEN(4,FILE=NAMH2O,STATUS='OLD')
C      ------------------------------------------------------------------
C       READ IN THE TITLE OF THE ZONE FROM THE DATA FILE
      READ(4,'(A)')TITLE
      WRITE(1,305)
305   FORMAT(/,5X,'ENTER RUN NUMBER (E.G. 0001) FOUR DIGITS'
     2,' AND DATE (E.G. 21-10-78)')
      READ(1,'(A)')RUNDAT
      WRITE(1,310)
310   FORMAT(/,5X,'FOR THE FOLLOWING SWITCHES ENTER THE NUMBER'
     2,' CORRESPONDING TO THE STATEMENT')
      WRITE(1,315)
315   FORMAT(/,5X,'IPORF:')
      WRITE(1,320)
320   FORMAT(5X,'1= FINAL POROSITY IS FROM NEUTRON DENSITY CROSSPLOT')
      WRITE(1,325)
325   FORMAT(5X,'2= FINAL POROSITY IS AVERAGE OF SONIC PLUS'
     2,' NEUTRON DENSITY CROSSPLOT')
      WRITE(1,330)
330   FORMAT(5X,'3= FINAL POROSITY IS AVERAGE OF SIMPLEX PLUS SONIC'
     2,' PLUS NEUTRON DENSITY CROSSPLOT')
      READ(1,*)IPORF
      WRITE(1,335)
335   FORMAT(/,5X,'IHYDR= HYDROCARBON DETECTION SWITCH (I.E.'
     2,' IS Rxo LOG PRESENT ?)')
      WRITE(1,340)
340   FORMAT(5X,'1= YES , 0= NO')
      READ(1,*)IHYDR
      WRITE(1,345)
345   FORMAT(/,5X,'IPL= PLOT SWITCH (1= YES , 0= NO)')
      READ(1,*)IPL
      WRITE(1,350)
350   FORMAT(/,5X,'IRM= RESISTIVITY CORRECTION IN ORDER TO APPLY'
     2,' CORRECT BUTTERFLY CHART CORRECTION FOR Rt')
      WRITE(1,355)
355   FORMAT(5X,'1= LL8, ILM, ILD;  2= Rxo, LLs, LLd;')
      WRITE(1,360)
360   FORMAT(5X,'0= NO Rm LOG OR SOME OTHER RESISTIVITY'
     2,' COMBINATION IS PRESENT')
      READ(1,*)IRM
      WRITE(1,365)
365   FORMAT(/,5X,'MDPH= METRIC DEPTH (1= METRES; 0= FEET)')
      READ(1,*)MDPH
      WRITE(1,370)
370   FORMAT(/,5X,'MTAC= METRIC INTERVAL TRANSIT TIME')
      WRITE(1,375)
375   FORMAT(5X,'1= MICROSECONDS/METRE; 0= MICROSECONDS/FOOT')
      READ(1,*)MTAC
      WRITE(1,380)
```

```
380   FORMAT(/,5X,'MTEM= METRIC TEMPERATURE (1= CENTIGRADE;'
     2,' 2= FAHRENHEIT)')
      READ(1,*)MTEM
      WRITE(1,385)
385   FORMAT(/,5X,'LUN= INTERMEDIATE CALCULATIONS PRINT-OUT (DEBUG)')
      WRITE(1,387)
387   FORMAT(5X,'6= YES; 11= NO , NO OTHER VALUES ARE PERMITTED')
      READ(1,*)LUN
      WRITE(1,390)
390   FORMAT(/,5X,'NLTYPE= TYPE OF NEUTRON LOG (1= SNP; 2= CNL;'
     2,' 3= API UNITS (E.G. GNT TOOL))')
      READ(1,*)NLTYPE
      WRITE(1,395)
395   FORMAT(/,5X,'IPRINT= 6, NORMAL OUTPUT PRINTING DEVICE'
     2,' =7 FOR GOULD PRINTER')
      READ(1,*)IPRINT
      WRITE(1,400)
400   FORMAT(/,5X,'ISP= IS SP RELIABLE; 1= YES, 0= NO')
      READ(1,*)ISP
      WRITE(1,410)
410   FORMAT(/,5X,'ENTER THE RESISTIVITY OF THE MUD FILTRATE AND THE'
     2,' TEMPERATURE AT WHICH IT WAS EVALUATED')
      WRITE(1,411)
411   FORMAT(5X,'(SEPARATE BY A COMMA)')
      READ(1,*)RMF,TMF
      WRITE(1,420)
420   FORMAT(/,5X,'ENTER THE FORMATION TEMPERATURE')
      READ(1,*)TEM
      IF(MTEM.EQ.1)RMF=RMF*(TMF+21.5)/(TEM+21.5)
      IF(MTEM.EQ.2)RMF=RMF*(TMF+6.77)/(TEM+6.77)
      WRITE(1,425)
425   FORMAT(/,5X,'ENTER THE NEUTRON LOG CORRECTION FOR THE'
     2,' BOREHOLE ENVIRONMENT')
      WRITE(1,430)
430   FORMAT(5X,'(REFERENCE CHARTS Por-14b AND Por-14bm OF THE LOG'
     2,' INTERPRETATION CHART BOOK, 1979 EDITION)')
      READ(1,*)DELPOR
      WRITE(1,435)
435   FORMAT(/,5X,'ENTER THE HYDROCARBON DENSITY (G/CC)')
      READ(1,*)DENHYD
      WRITE(1,440)
440   FORMAT(/,5X,'ENTER THE BOREHOLE DIAMETER (INCHES)')
      READ(1,*)BORE
200   WRITE(1,202)
202   FORMAT(/,5X,'ENTER THE ARCHIE COEFFICIENT')
      READ(1,*)ARCHIE
C
C      SET UP THE INITIAL VALUES
      FPMAX=-1.0
      CPMIN=6.0E+5
      SHPMAX=-100.0
```

```
      GRYMIN=1000.0
      GRYMAX=-1000.0
      SPMAX=-1000.0
      SPMIN=1000.0
      DENMF=0.0
      TACF=0.0
      TACMA=0.0
      DENMA=0.0
      SSP=0.0
      RSH=0.0
      DENSH=0.0
      TACSH=0.0
      PORNSH=0.0
C      ------------------------------------------------------------------
C      START OF THE CALCULATIONS
C      XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
C      READ IN THE VARIABLES
      I=1
20    READ(4,*,END=405)DEPTH(I),GR(I),DEN(I),NEU(I),TT(I),
     1SP(I),MSFL(I),RLS(I),RLD(I)
      IF(DEPTH(I).EQ.-1.0)GOTO 405
C
C      WRITE OUT THE HEADING EVERY 50 SAMPLE POINTS
      IF(I.EQ.1.OR.I.EQ.50.OR.I.EQ.100.OR.I.EQ.150
     2.OR.I.EQ.200.OR.I.EQ.250.OR.I.EQ.300.OR.I.EQ.350)THEN
      WRITE(1,14)
14    FORMAT(/,5X,'DEPTH',4X,'GAMMA',4X,'PHI',3X,'RHOma',5X,'TTma',6X
     2,'Rdeep',5X,'Rt',6X,'Rw(ARCHIE)---->SALINITY',4X,'Rw(RATIO)'
     3,'---->SALINITY')
      WRITE(1,6)
6     FORMAT(5X,112('-'))
      END IF
C
C      CORRECT THE NEUTRON POROSITY
      NEU(I)=NEU(I)+DELPOR
C      ------------------------------------------------------------------
C      THIS SECTION CALCULATES 'PHIX' THE CROSSPLOT POROSITY
      DENMF=1.0
C      CALCULATE THE POROSITY FROM THE DENSITY LOG
      PHID=(2.71-DEN(I))/(2.71-DENMF)
C      CALCULATE THE CROSSPLOT POROSITY 'PHIX'
      PHIX(I)=(PHID+NEU(I))/2.0
C      ------------------------------------------------------------------
C      RHOMA= THE APPARANT GRAIN DENSITY OR MATRIX DENSITY
      RHOMA(I)=(DEN(I)-PHIX(I))/(1.0-PHIX(I))
C      ------------------------------------------------------------------
C      CALCULATE THE NEUTRON DENSITY FREQUENCY PLOT DATA
      IF(PHIX(I).LT.-0.10)PHIX(I)=-0.10
      IF(PHIX(I).GT.0.60)PHIX(I)=0.60
      IF(RHOMA(I).LT.2.40)RHOMA(I)=2.40
      IF(RHOMA(I).GT.3.30)RHOMA(I)=3.30
```

```
      IFP=PHIX(I)*100.0+21.0
      JFP=(RHOMA(I)-2.4)*50.0+1.0
      FPLT(IFP,JFP)=FPLT(IFP,JFP)+1.0
      IF(FPLT(IFP,JFP).GT.FPMAX) FPMAX=FPLT(IFP,JFP)
C      ------------------------------------------------------------------
C       THIS SECTION CALCULATES THE APPARENT MATRIX TRANSIT TIME
C       FROM THE SONIC LOG
      TTF=620.0
      IF(MTAC.EQ.0)TTF=189.0
      TTMA(I)=(TT(I)-TTF*PHIX(I))/(1.0-PHIX(I))
      IF(TT(I).EQ.0.0)TTMA(I)=0.0
C      ------------------------------------------------------------------
C       THIS SECTION CALCULATES TRUE FORMATION RESISTIVITY
      IF(IRM.EQ.1.AND.IHYDR.EQ.1)THEN
C       THIS SECTION IS TAKEN DIRECTLY FROM THE NLOG4 PROGRAM
C       SUBROUTINE "DIND" WRITTEN BY L.E.KURYLOWICZ
      RLL8=MSFL(I)
      RILM=RLS(I)
      RILD=RLD(I)
      A=(RLL8/RILD)-1.0
      B=(RILM/RILD)-1.0
      C=A/B
      BB=(0.59*A)-(2.21*C)+1.35
      CC=-((1.44*A)-(2.47*C)+2.76)
      D=-0.5*(SQRT((BB*BB)-(4.0*CC))+BB)
      IF(D.GT.1.0)THEN
      RT(I)=RILD
      ELSE IF(D.LT.0.4)THEN
      RT(I)=0.4*RILD
      ELSE
      RT(I)=RILD*D
      END IF
      END IF
C
      IF(IRM.EQ.2.AND.IHYDR.EQ.1)THEN
C       THIS SECTION CALCULATES RT FROM THE LATTERLOG BUTTERFLY CHART
      A=RLD(I)/MSFL(I)
      B=RLD(I)/RLS(I)
      IF(A.LE.1.0)RT(I)=1.7*RLD(I)-0.7*RLS(I)
      IF(B.LE.1.1)RT(I)=1.1*RLD(I)
      IF(A.GT.1.0.AND.B.GT.1.1)THEN
      C=(RLS(I)/MSFL(I))*(RLD(I)-MSFL(I))/(RLD(I)-RLS(I))
      RT(I)=(2.18*C*RLD(I))/(1.78*C-1.0)
      END IF
      END IF
C
C       THIS SECTION CALCULATES RT WHEN NO MUDCAKE RESISTIVITY LOG IS PRE
      IF(IHYDR.EQ.0)THEN
      B=RLD(I)/RLS(I)
      IF(B.GE.1.0)RT(I)=1.7*RLD(I)-0.7*RLS(I)
      IF(B.LT.1.0)RT(I)=2.4*RLD(I)-1.4*RLS(I)
```

```
      END IF
C
C      CHECK THAT RT IS NOT OUTSIDE MAXIMUM BOUNDS
      IF(RT(I).LE.0.0.OR.RT(I)/RLD(I).GT.2.0)RT(I)=RLD(I)
C      ------------------------------------------------------------------
C      CALCULATE THE WATER RESISTIVITY
      RWA=RT(I)*(PHIX(I)*PHIX(I))/ARCHIE
      RWR=RMF*RT(I)/MSFL(I)
      IF(IHYDR.EQ.2)RWR=0.0
C      ------------------------------------------------------------------
C      CHECK THAT RW IS NOT BELOW THE WORKING LIMIT FOR
C      THE CALCULATION OF SALINITY. IE. Rw > 0.01 OHM.M IS ACCEPTABLE
C      ------------------------------------------------------------------
C      PRINT OUT THE RESULTS
      IF(RWA.GE.0.01.AND.RWR.GE.0.01)THEN
      CALL SALWTR(SALWA,RWA,TEM,MTEM)
      CALL SALWTR(SALWR,RWR,TEM,MTEM)
      WRITE(1,15)DEPTH(I),GR(I),PHIX(I),RHOMA(I),TTMA(I),RLD(I),RT(I)
     2,RWA,SALWA,RWR,SALWR
15    FORMAT(1X,F10.1,3X,F5.1,2X,F5.3,3X,F5.3,4X,F6.2,3X,F6.1
     2,3X,F6.1,5X,F6.3,7X,F10.1,5X,F6.3,6X,F10.1)
      ELSE
      WRITE(1,16)DEPTH(I),GR(I),PHIX(I),RHOMA(I),TTMA(I),RLD(I)
16    FORMAT(1X,F10.1,3X,F5.1,2X,F5.3,3X,F5.3,4X
     2,F6.2,3X,F6.1,4X,' RESISTIVITY ANOMALY')
      GOTO 19
      END IF
C      ------------------------------------------------------------------
C      FIND THE CLEANEST POINT AND THE DEPTH AT WHICH IT OCCURS
      CP=GR(I)*RT(I)
      IF(CP.LT.CPMIN)THEN
      ICP=I
      CPMIN=CP
      RWMIN=RWA
      DPHMIN=DEPTH(I)
      END IF
C
C      FIND THE BEST SHALE POINT
19    SHP=NEU(I)-PHID
      IF(SHP.GT.SHPMAX)THEN
      SHPMAX=SHP
      ISHP=I
      END IF
C
C      FIND THE MAXIMUM GAMMA RAY VALUE
      IF(GR(I).GT.GRYMAX)GRYMAX=GR(I)
C
C
C      FIND THE MINIMUM GAMMA RAY VALUE
      IF(GR(I).LT.GRYMIN)GRYMIN=GR(I)
C
```

```
C       FIND THE MAXIMUM AND MINIMUM VALUES OF SP
      IF(SP(I).GT.SPMAX)SPMAX=SP(I)
      IF(SP(I).LT.SPMIN)SPMIN=SP(I)
C       XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      I=I+1
      GOTO 20
C       ----------------------------------------------------------------
C       CALCULATE THE NUMBER OF SAMPLE POINTS
405   NSP=I-1
C
C       FIND THE SSP AND SPMIN
      IF(RMF.GE.RWMIN)THEN
      SSP=SPMIN
      SPMIN=SPMAX
      ELSE
      SSP=SPMAX
      END IF
C       ----------------------------------------------------------------
C       FIND THE SHALE AND MATRIX PARAMETERS
      NSHP=0.0
      NCP=0.0
      PHISH=0.0
      RSH=0.0
      RHOSH=0.0
      RHOCP=0.0
      TTSH=0.0
      TTCP=0.0
C
C       SET THE UPPER AND LOWER "AVERAGE" CUTOFF LIMITS
      U=SHPMAX*0.90
      L=CPMIN*1.2
C
      DO 30 K=1,NSP
      PHID=(2.71-DEN(K))/(2.71-DENMF)
      IF((NEU(K)-PHID).GE.U)THEN
      NSHP=NSHP+1.0
      PHISH=PHISH+PHIX(K)
      RSH=RSH+RT(K)
      RHOSH=RHOSH+RHOMA(K)
      TTSH=TTSH+TTMA(K)
      END IF
      IF(GR(K)*RT(K).LE.L)THEN
      NCP=NCP+1.0
      RHOCP=RHOCP+RHOMA(K)
      TTCP=TTCP+TTMA(K)
      END IF
30    CONTINUE
C
C       FIND THE AVERAGE VALUES
      PHSHAV=PHISH/NSHP
      RSHAV=RSH/NSHP
```

```
      RHSHAV=RHOSH/NSHP
      TTSHAV=TTSH/NSHP
      RHCPAV=RHOCP/NCP
      TTCPAV=TTCP/NCP
C      ------------------------------------------------------------------
C       PRINT OUT THE PARAMETERS DETERMINED
      WRITE(1,43)
43    FORMAT(/,5X,'FORMATION WATER PROPERTIES')
      WRITE(1,90)
90    FORMAT(5X,26('-'))
      WRITE(1,44)
44    FORMAT(5X,'CLEANEST POINT USING THE ARCHIE EQUATION:')
      WRITE(1,45)RWMIN
45    FORMAT(5X,'(1) Rw= ',F6.4,' OHM-M')
      IF(MDPH.EQ.1)THEN
      WRITE(1,46)DPHMIN
46    FORMAT(5X,'DEPTH= ',F6.1,' METRES')
      ELSE
      WRITE(1,49)DPHMIN
49    FORMAT(5X,'DEPTH= ',F6.1,' FEET')
      END IF
      IF(MTEM.EQ.1)THEN
      WRITE(1,47)TEM
47    FORMAT(5X,'FORMATION TEMPERATURE= ',F5.1,' DEGREES CENTIGRADE')
      ELSE
      WRITE(1,50)TEM
50    FORMAT(5X,'FORMATION TEMPERATURE= ',F5.1,' DEGREES FARENHEIT')
      END IF
      CALL SALWTR(SALW,RWMIN,TEM,MTEM)
      WRITE(1,48)SALW
48    FORMAT(5X,'WATER SALINITY= ',F10.1,' PPM.',/)
      WRITE(1,60)
60    FORMAT(5X,'MUD FILTRATE PROPERTIES')
      WRITE(1,91)
91    FORMAT(5X,23('-'))
      WRITE(1,61)RMF
61    FORMAT(5X,'Rmf= ',F5.4,' OHM-M AT FORMATION TEMPERATURE')
      CALL SALWTR(SALMF,RMF,TEM,MTEM)
      WRITE(1,62)SALMF
62    FORMAT(5X,'MUD FILTRATE SALINITY= ',F10.1,' PPM.',/)
      WRITE(1,70)
70    FORMAT(5X,'SHALE PROPERTIES')
      WRITE(1,93)
93    FORMAT(5X,16('-'))
      IF(MDPH.EQ.1)THEN
      WRITE(1,51)DEPTH(ISHP)
51    FORMAT(5X,'SHALIEST POINT AT A DEPTH OF ',F6.1,' METRES')
      ELSE
      WRITE(1,52)DEPTH(ISHP)
52    FORMAT(5X,'SHALIEST POINT AT A DEPTH OF ',F6.1,' FEET')
      END IF
```

```
      WRITE(1,71)GRYMAX
71    FORMAT(5X,'(2) GAMMA RAY VALUE= ',F5.1,' API UNITS')
      WRITE(1,72)SPMIN
72    FORMAT(5X,'(3) SP BASE LINE VALUE= ',F5.1,' mV')
      WRITE(1,74)PHSHAV
74    FORMAT(5X,'(4) NEUTRON LOG POROSITY= ',F5.3)
      WRITE(1,75)RHSHAV
75    FORMAT(5X,'(5) DENSITY LOG VALUE= ',F5.3,' G/CC')
      IF(MTAC.EQ.1)THEN
      WRITE(1,76)TTSHAV
76    FORMAT(5X,'(6) SHALE TRANSIT TIME= ',F6.2
     2,' uS/metre.')
      ELSE
      WRITE(1,78)TTSHAV
78    FORMAT(5X,'(6) SHALE TRANSIT TIME= ',F6.2
     2,' uS/ft.')
      END IF
      WRITE(1,77)RSHAV
77    FORMAT(5X,'(7) SHALE RESISTIVITY= ',F6.2,' OHM-M',/)
      WRITE(1,80)
80    FORMAT(5X,'MATRIX PROPERTIES')
      WRITE(1,94)
94    FORMAT(5X,17('-'))
      WRITE(1,81)GRYMIN
81    FORMAT(5X,'(8)  GAMMA RAY VALUE= ',F5.1,' API UNITS')
      WRITE(1,82)SSP
82    FORMAT(5X,'(9)  SP= ',F5.1,' mV')
      WRITE(1,84)RHCPAV
84    FORMAT(5X,'(10) APPARENT MATRIX DENSITY= ',F5.3,' G/CC')
      IF(MTAC.EQ.1)THEN
      WRITE(1,85)TTCPAV
85    FORMAT(5X,'(11) APPARENT MATRIX TRANSIT TIME= ',F6.2
     2,' uS/metre.')
      ELSE
      WRITE(1,86)TTCPAV
86    FORMAT(5X,'(11) APPARENT MATRIX TRANSIT TIME= ',F6.2
     2,' uS/ft.')
      END IF
C      ------------------------------------------------------------------
C      TRANSFER DATA FROM FPLT TO PIC TO FORM THE CHARACTER ARRAY
      DO 96 ISCL=1,81
      DO 96 JSCL=1,46
      FP=FPLT(ISCL,JSCL)*10/FPMAX
      IF(FP.EQ.0)PIC(ISCL,JSCL)=' '
      IF(FP.EQ.1)PIC(ISCL,JSCL)='0'
      IF(FP.EQ.2)PIC(ISCL,JSCL)='1'
      IF(FP.EQ.3)PIC(ISCL,JSCL)='2'
      IF(FP.EQ.4)PIC(ISCL,JSCL)='3'
      IF(FP.EQ.5)PIC(ISCL,JSCL)='4'
      IF(FP.EQ.6)PIC(ISCL,JSCL)='5'
      IF(FP.EQ.7)PIC(ISCL,JSCL)='6'
```

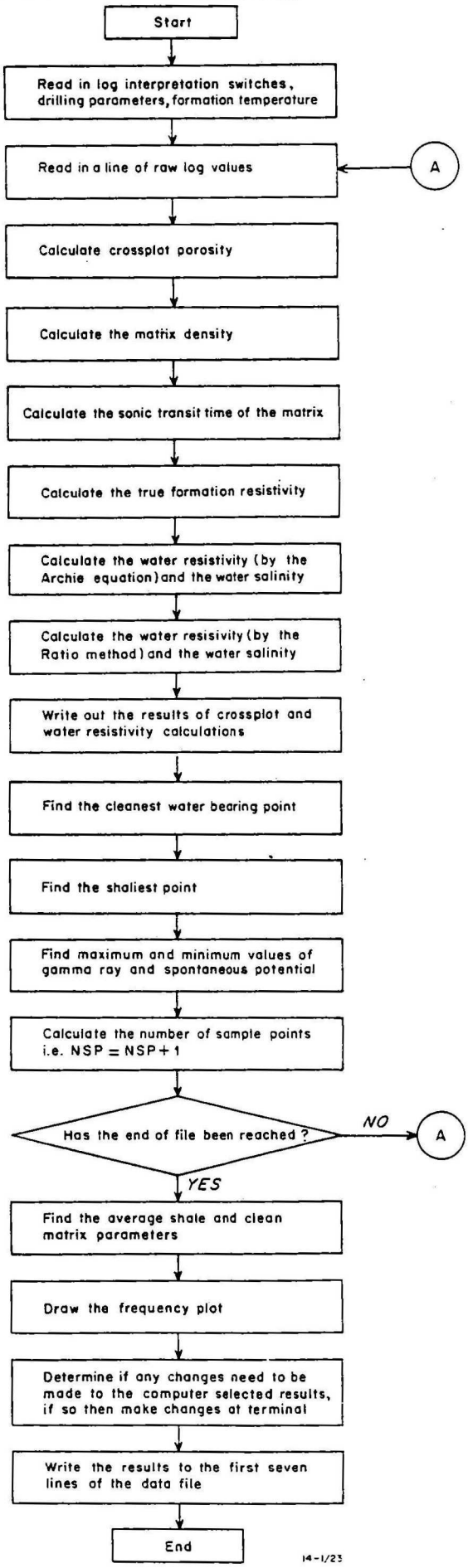
```
      IF(FP.EQ.8)PIC(ISCL,JSCL)='7'
      IF(FP.EQ.9)PIC(ISCL,JSCL)='8'
      IF(FP.GE.10)PIC(ISCL,JSCL)='9'
96    CONTINUE
C
C      FORM THE BORDERS OF THE PLOT WITH PLUS SIGNS
      DO 130 IY=11,81,10
      DO 130 JY=1,46
      IF(PIC(IY,JY).EQ.' ')PIC(IY,JY)='+'
130   CONTINUE
      DO 131 JX=1,46,5
      DO 131 IX=11,81
      IF(PIC(IX,JX).EQ.' ')PIC(IX,JX)='+'
131   CONTINUE
C
C      FORM THE DENSITY SCALE VALUES ON THE VERTICAL AXIS
      DO 135 JD=1,46,5
      PIC(5,JD)='2'
      IF(JD.GE.31)PIC(5,JD)='3'
      PIC(6,JD)='.'
      IF(JD.EQ.1)PIC(7,JD)='4'
      IF(JD.EQ.6)PIC(7,JD)='5'
      IF(JD.EQ.11)PIC(7,JD)='6'
      IF(JD.EQ.16)PIC(7,JD)='7'
      IF(JD.EQ.21)PIC(7,JD)='8'
      IF(JD.EQ.26)PIC(7,JD)='9'
      IF(JD.EQ.31)PIC(7,JD)='0'
      IF(JD.EQ.36)PIC(7,JD)='1'
      IF(JD.EQ.41)PIC(7,JD)='2'
      IF(JD.EQ.46)PIC(7,JD)='3'
      PIC(8,JD)='0'
135   CONTINUE
C
C      PRINT OUT THE HEADING AND POROSITY SCALES ON THE HORIZONTAL AXIS
      WRITE(1,133)
133   FORMAT(///,25X,'CROSSPLOTTED POROSITY (PHI) VERSUS '
     2,'MATRIX DENSITY (RHOma)')
      WRITE(1,136)
136   FORMAT(25X,57('-'))
      WRITE(1,134)
134   FORMAT(/,18X,'-0.10',6X,'0.0',7X,'0.10',6X,'0.20',6X,
     2'0.30',6X,'0.40',6X,'0.50',6X,'0.60')
C
C      PRINT OUT THE CHARACTER ARRAY "PIC"
      DO 92 JPLT=1,46
92    WRITE(1,95)(PIC(IPLT,JPLT),IPLT=1,81)
95    FORMAT(10X,81A)
C      ------------------------------------------------------------------
C      DETERMINE IF ANY PARAMETER NEEDS TO BE ALTERED
140   WRITE(1,100)
100   FORMAT(//,5X,'DO YOU WANT TO CHANGE ANYTHING ?')
```

```
      WRITE(1,101)
101   FORMAT(5X,'TO ALTER A VARIABLE TYPE IN THE BRACKETED NUMBER')
      WRITE(1,102)
102   FORMAT(5X,'FOR NO CHANGE TYPE IN 0 (=ZERO)')
      READ(1,111)Q
111   FORMAT(I2)
      IF(Q.EQ.1)THEN
      WRITE(1,103)
103   FORMAT(5X,'ENTER NEW Rw')
      READ(1,*)RWMIN
      END IF
      IF(Q.EQ.2)THEN
      WRITE(1,104)
104   FORMAT(5X,'ENTER NEW SHALE GAMMA RAY')
      READ(1,*)GRYMAX
      END IF
      IF(Q.EQ.3)THEN
      WRITE(1,105)
105   FORMAT(5X,'ENTER NEW SP BASE LINE VALUE')
      READ(1,*)SPMIN
      END IF
      IF(Q.EQ.4)THEN
      WRITE(1,106)
106   FORMAT(5X,'ENTER NEW NEUTRON SHALE POROSITY')
      READ(1,*)PHSHAV
      END IF
      IF(Q.EQ.5)THEN
      WRITE(1,107)
107   FORMAT(5X,'ENTER NEW SHALE DENSITY')
      READ(1,*)RHSHAV
      END IF
      IF(Q.EQ.6)THEN
      WRITE(1,114)
114   FORMAT(5X,'ENTER NEW SHALE TRANSIT TIME')
      READ(1,*)TTSHAV
      END IF
      IF(Q.EQ.7)THEN
      WRITE(1,116)
116   FORMAT(5X,'ENTER NEW SHALE RESISTIVITY')
      READ(1,*)RSHAV
      END IF
      IF(Q.EQ.8)THEN
      WRITE(1,108)
108   FORMAT(5X,'ENTER NEW CLEAN GAMMA RAY VALUE')
      READ(1,*)GRYMIN
      END IF
      IF(Q.EQ.9)THEN
      WRITE(1,109)
109   FORMAT(5X,'ENTER NEW SSP')
      READ(1,*)SSP
      END IF
```

```
      IF(Q.EQ.10)THEN
      WRITE(1,110)
110   FORMAT(5X,'ENTER NEW MATRIX DENSITY')
      READ(1,*)RHCPAV
      END IF
      IF(Q.EQ.11)THEN
      WRITE(1,115)
115   FORMAT(5X,'ENTER NEW MATRIX TRANSIT TIME')
      READ(1,*)TTCPAV
      END IF
      IF(Q.NE.0.0)GOTO140
C      ------------------------------------------------------------
C       INSERT THE VALUES INTO THE DATA FILE
      REWIND(4)
      PMF=SALMF/1.0E+6
      WRITE(4,'(A)')TITLE
      WRITE(4,'(A)')RUNDAT
      WRITE(4,120)IPORF,IHYDR,IPL,IRM,MDPH,MTAC,MTEM,LUN,NLTYPE,IPRINT
     1,ISP
120   FORMAT(1X,I1,',',I1,',',I1,',',I1,',',I1,',',I1,',',I1,',',I2,
     2',',I1,',',I1,',',I1)
      WRITE(4,121)NSP,TEM,PMF,RMF,DENMF,TTF,DELPOR
121   FORMAT(1X,I3,',',F5.1,',',F5.3,',',F5.3,',',F3.1,',',F5.1,
     2',',F6.3)
      WRITE(4,122)GRYMIN,RHCPAV,TTCPAV,SSP
122   FORMAT(1X,F5.1,',',F5.3,',',F5.1,',',F5.1)
      WRITE(4,123)GRYMAX,RSHAV,RHSHAV,TTSHAV
     2,PHSHAV,SPMIN
123   FORMAT(1X,F5.1,',',F4.1,',',F5.3,',',F5.1,',',F5.3,',',F5.1)
      WRITE(4,124)RWMIN,DENHYD,BORE
124   FORMAT(1X,F6.4,',',F5.3,',',F6.3)
      DO 125 J=1,NSP
      NEU(J)=NEU(J)-DELPOR
      WRITE(4,126)DEPTH(J),GR(J),DEN(J),NEU(J),TT(J)
     1,SP(J),MSFL(J),RLS(J),RLD(J)
126   FORMAT(1X,F6.1,',',F5.1,',',F5.3,',',F4.3,',',F5.1,',',F5.1
     2,',',F6.1,',',F6.1,',',F6.1)
125   CONTINUE
      WRITE(4,127)
127   FORMAT('-1')
C      ------------------------------------------------------------
      CLOSE(4)
      STOP
      END
C      ------------------------------------------------------------
C       COMPUTE THE FLUID SALINITY
      SUBROUTINE SALWTR(SAL,R,T,M)
      IF(M.EQ.1)T=T*9.0/5.0+32.0
      SAL=(3.0E+5/(R*(T+7.0)-1.0))**1.05
      IF(M.EQ.1)T=5.0/9.0*(T-32.0)
      RETURN

C      ------------------------------------------------------------
      END
      END$
```

(ii) Program Flowchart



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APPENDIX 1

Definitions of each of the computer programs shown on Figure 1 are given below:

(1) SIMUL, used to convert digitised data being entered into the computer from the digitiser into X-Y co-ordinates.

(2) DIGFX, used to locate and correct digitising errors.

(3) XYPLT, converts X-Y co-ordinates into scaled raw wireline log data.

(4) RW, computes wireline log interpretation parameters of the 100% shale and 100% water zones (if present) from the scaled raw wireline log data file.

(5) LOG4, a shaly-sand wireline log interpretation model which uses the simandoux equation to calculate water saturation.

(6) DW, a shaly-sand wireline log interpretation model which uses the dual water model equation to calculate water saturation.

(7) TVD, converts measured depths in a wireline log data file to true vertical depths below a chosen datum.

(8) PLOG, plots out a complete suite of digitised logs multiplied by a preselected x and y scaling factor for the purposes of correlating log character across a field.

(9) LGPLT, plots out pre-interpreted wireline log data (generated by the second pass) on a 1:200 scale.