CHAPTER FOUR

LOW RESISTIVITY MEASURMENT

In this chapter we will show the methodology of identifying the zone of LRLC in two wells in the study area.

4.1 Application:

4.1.1 Program work flow:

After the well log done the composite well log data was saved as (Las file form)

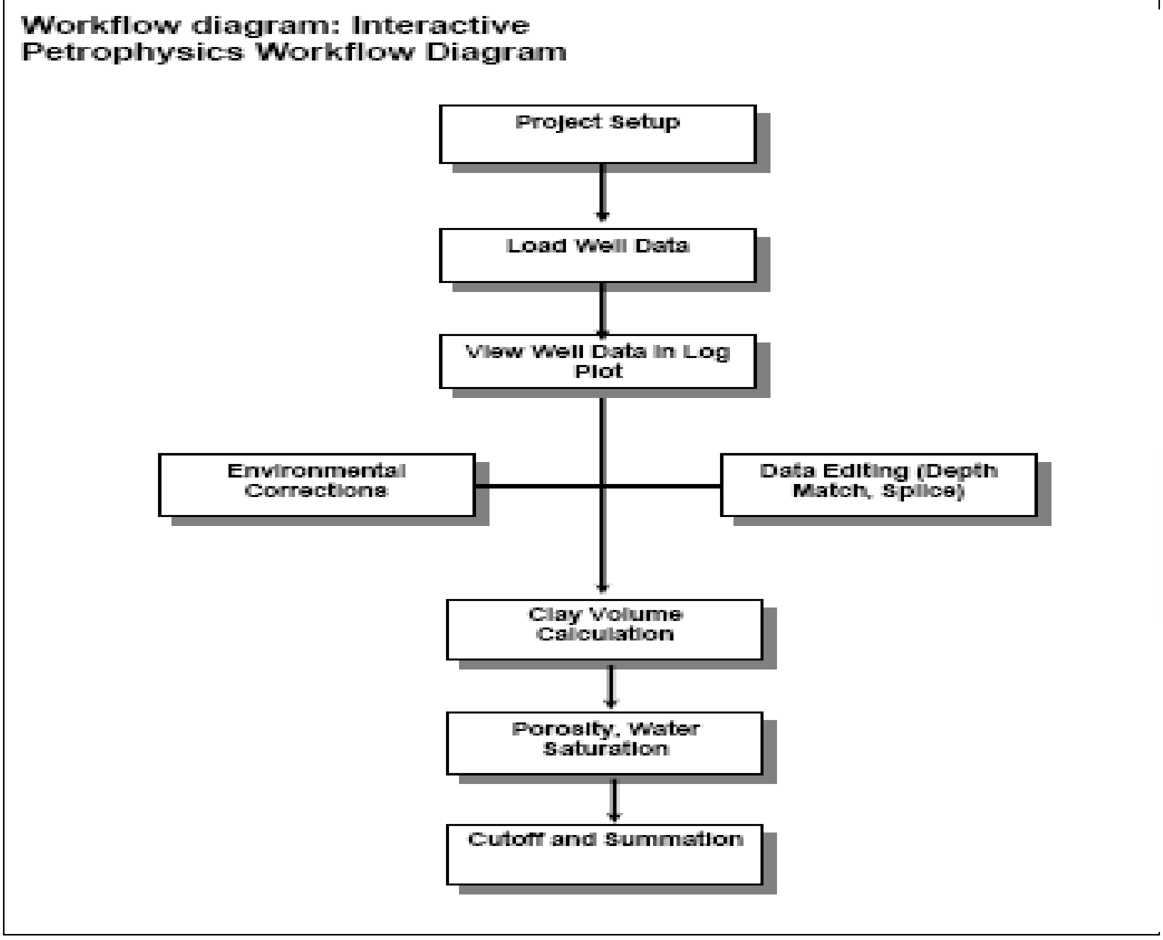

Fig. (4.1) work flow using IP

4.1.2 Step One:

Loading data:

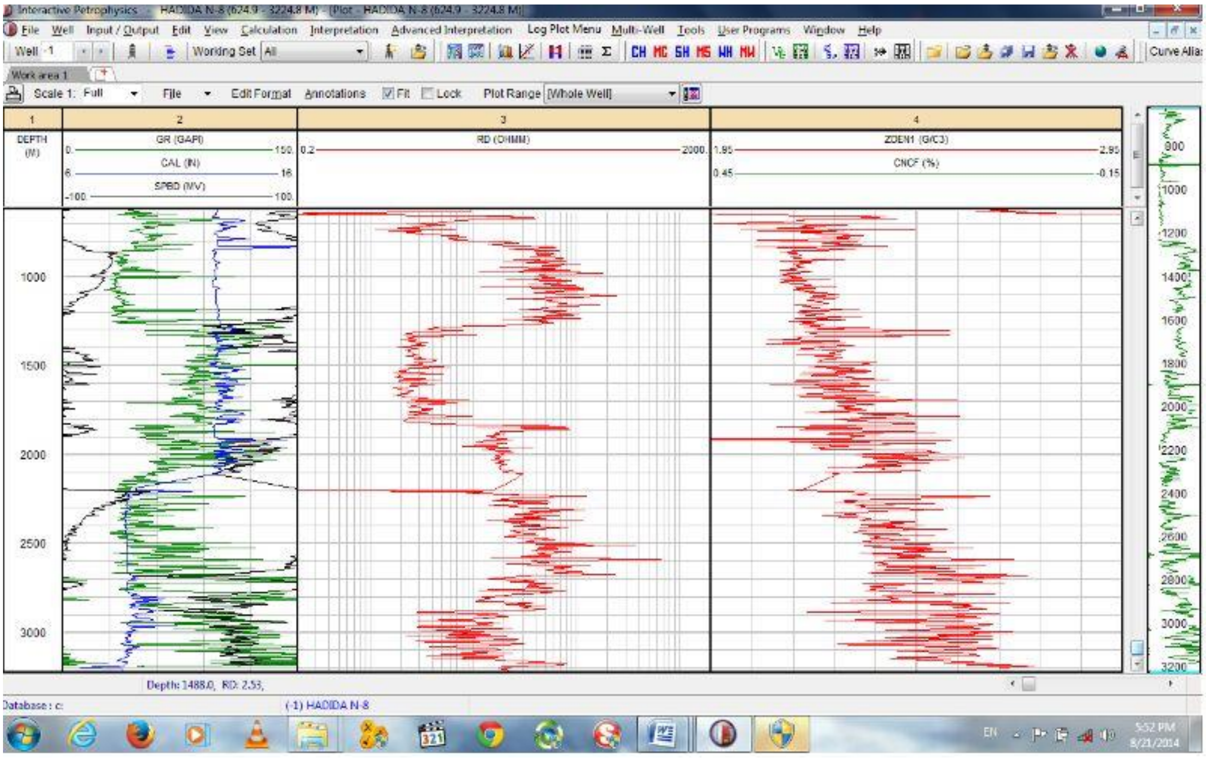

Fig. (4.2) showing data load

4.1.3 Step Two:

Calculate the clay volume by using:

- **Gamma Ray:**

The Gamma Ray clay indicator (Vcl_{GR}) can be calculated using the following methods:

- **Linear :**

$$I_{sh} = \frac{GR - GR_{cl}}{GR_{sh} - GR_{cl}} \qquad (4.1)$$

GR=log response in the zone of interest, API units.

GRcl= log response in clean beds, API units.

GRsh= log response in shale beds, API units.

The following plot shows the different gamma ray V clay relationships

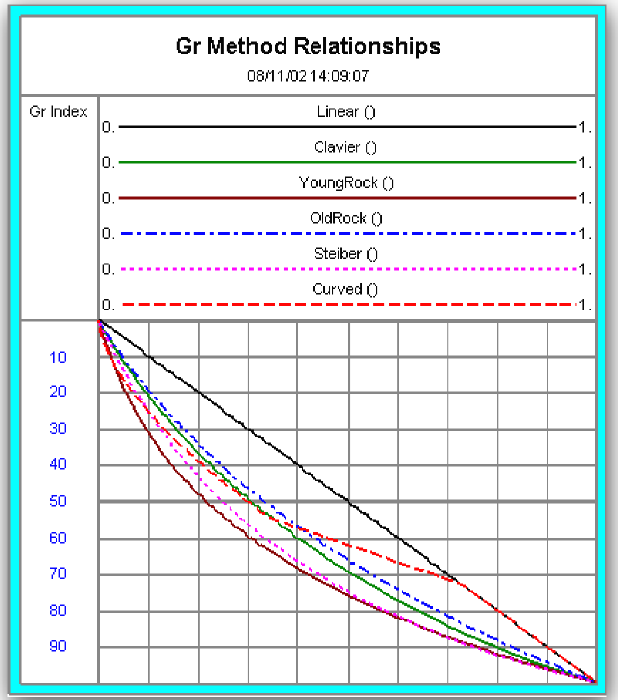

Fig. (4.3) Gr method relationship

The best way to calculate the clay volume by using gamma ray in IP is to make reasonable zonation in all well as what we doing in Fig (4.4). The greater the number of shale base line, the greater the intensity and by this method we can do that.

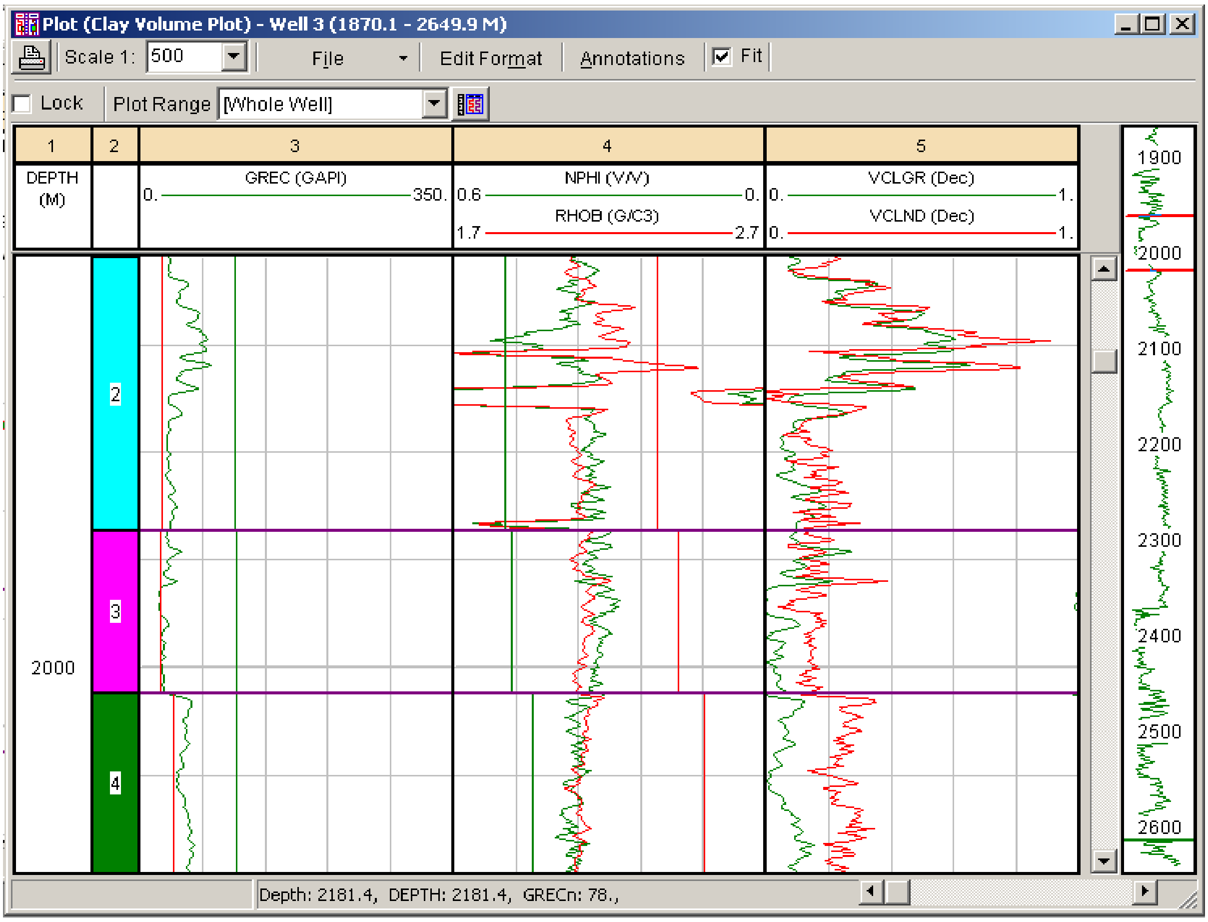

Fig. (4.4) reasonable zonation in all well

- **Curved :**

Z = $\mathbf{Vcl}_{GR}$ as above

$$Vcl_{GR} = 0.0006078(100 * z)^{1.58527} \quad (4.2)$$

For Z less than 0.55

For Z greater than 0.55 and less than 0.73

$$\mathbf{Vcl}_{GR} = 2.1212 * Z - 0.81667 \quad (4.3)$$

For Z greater than 0.73 and less than 1.0 VclGr = Z

- **Clavier :**

$$VCl_{Gr} = \sqrt{3.38 - (Z + 0.7)^2} \quad (4.4)$$

- **Stieber (South Louisiana Miocene and Pliocene) :**

$$\mathbf{Vcl}_{GR} = \frac{0.5*Z}{1.5-Z} \quad (4.5)$$

- **Larionov older rocks (Mesozoic) :**

$$\text{VclGr} = 0.333(2^{2*Z}-1) \quad (4.6)$$

- **Larionov younger rocks (Tertiary clastics) :**

$$\mathbf{Vcl}_{GR} = 0.08336(2^{3.7*Z} - 1) \quad (4.7)$$

- **Self-potential (SP):**

$$\mathbf{Vcl}_{SP} = \frac{SP-SPClean}{SPClay-SPClean} \quad (4.8)$$

- **Neutron:**

$$\mathbf{Vcl}_{Neu} = \sqrt{\frac{\text{Øneu}}{\text{Øneuclay}} * \frac{\text{Øneu} - \text{Øneuclean}}{\text{Øneuclay} - \text{Øneuclean}}} \quad (4.9)$$

- **Resistivity:**

$$Z = \frac{Rclay}{Rt} * \frac{(Rclean-Rt)}{(Rclean-R)} \quad (4.10)$$

For Rt greater than 2 x R clay then

$$\text{VclRes} = 0.5 * (2 * Z)^{0.67*(Z+1)} \quad (4.11)$$

Otherwise $\text{VclRes} = Z$

4.1.4 Step three:

Calculate Porosity and water Saturation:

Archie's equation, rewritten for saturation of the flushed zone, to determine moveable oil

$$\text{Sxo}=\sqrt{\frac{a}{\text{Ø}m} * \frac{Rxo}{Rmf}} \quad (4.12)$$

And Indonesian (Poupon-Leveaux) equation for calculating:

$$\frac{1}{\sqrt{Rt}} = \sqrt{\frac{\emptyset^{m}}{aRw}} + Vcl\,\frac{1-\frac{Vcl}{2}}{\sqrt{Rcl}} * Sw^{\frac{n}{2}} \qquad (4.13)$$

4.1.5 Step Four:

Cutoff and Summation:

Each depth in the data is considered a discrete interval, with the recorded depth being the centre of the interval. Therefore, when making averages over an interval, only half of the top and bottom depth increments are counted. The following diagram provides an example explaining how 'net reservoir' would be calculated:

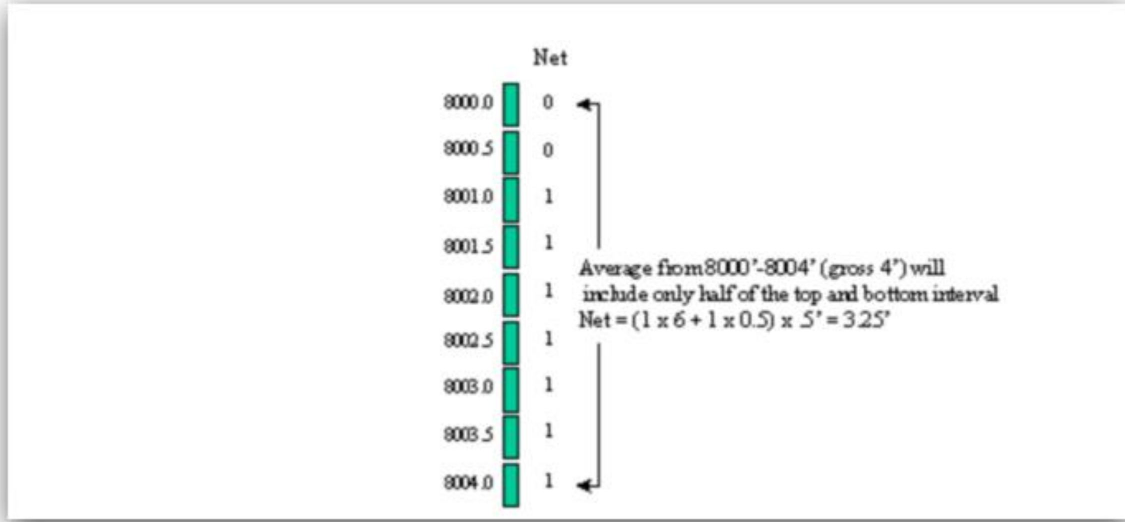

Fig. (4.5) an example explaining how the net reservoir would be

It is worth pointing out that the above equation misses out the zero points as in total there are nine intervals and so the equation should really be written like this:

Net = [((1 x 6) + (1 x 0)) + ((0.5 x 0) + (0.5 x 1))] x 0.5’ = 3.25 (4.14)

Average porosity:

$$\emptyset_{av} = \frac{\sum_{i=1}^{i=n} \emptyset i * hi}{\sum_{i=1}^{i=n} hi} \qquad (4.15)$$

Average water saturation:

$$S_{av} = 1 - \frac{\sum_{i=1}^{i=n} \emptyset i * h(1 - SW)}{\sum_{i=1}^{i=n} \emptyset i * hi} \qquad (4.16)$$

Average Clay volume:

$$Vcl_{av} = \frac{\sum_{i=1}^{i=n} Vcli * hi}{\sum_{i=1}^{i=n} hi} \qquad (4.17)$$

Where

i = i'th input value

h_i = i'th input interval

n = number of samples

4.2 Hadida low resistivity pay zone:

After well study in master log and comparison it with the well that result from software, we can tag out low resistivity pay zone.

4.2.1 Low resistivity pay zone in Hadida N-8:

- Interval of LRLC in Hadida N-8:1849.65 - 1856.51
- Resistivity RD= 22.08

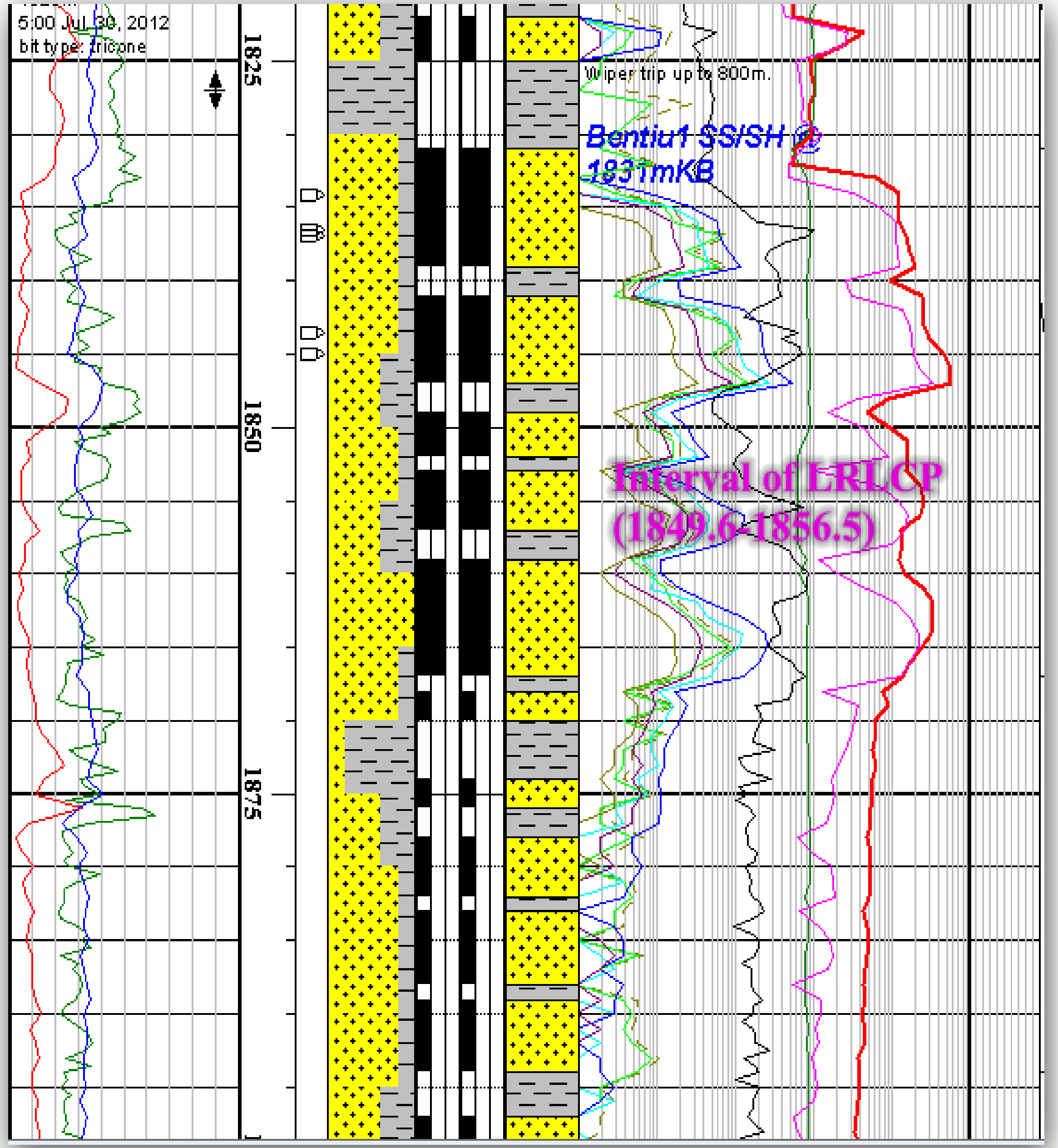

Fig. (4.6) Hadida N-8 master log Bentiu Formation (Aptian-Cenomanian).

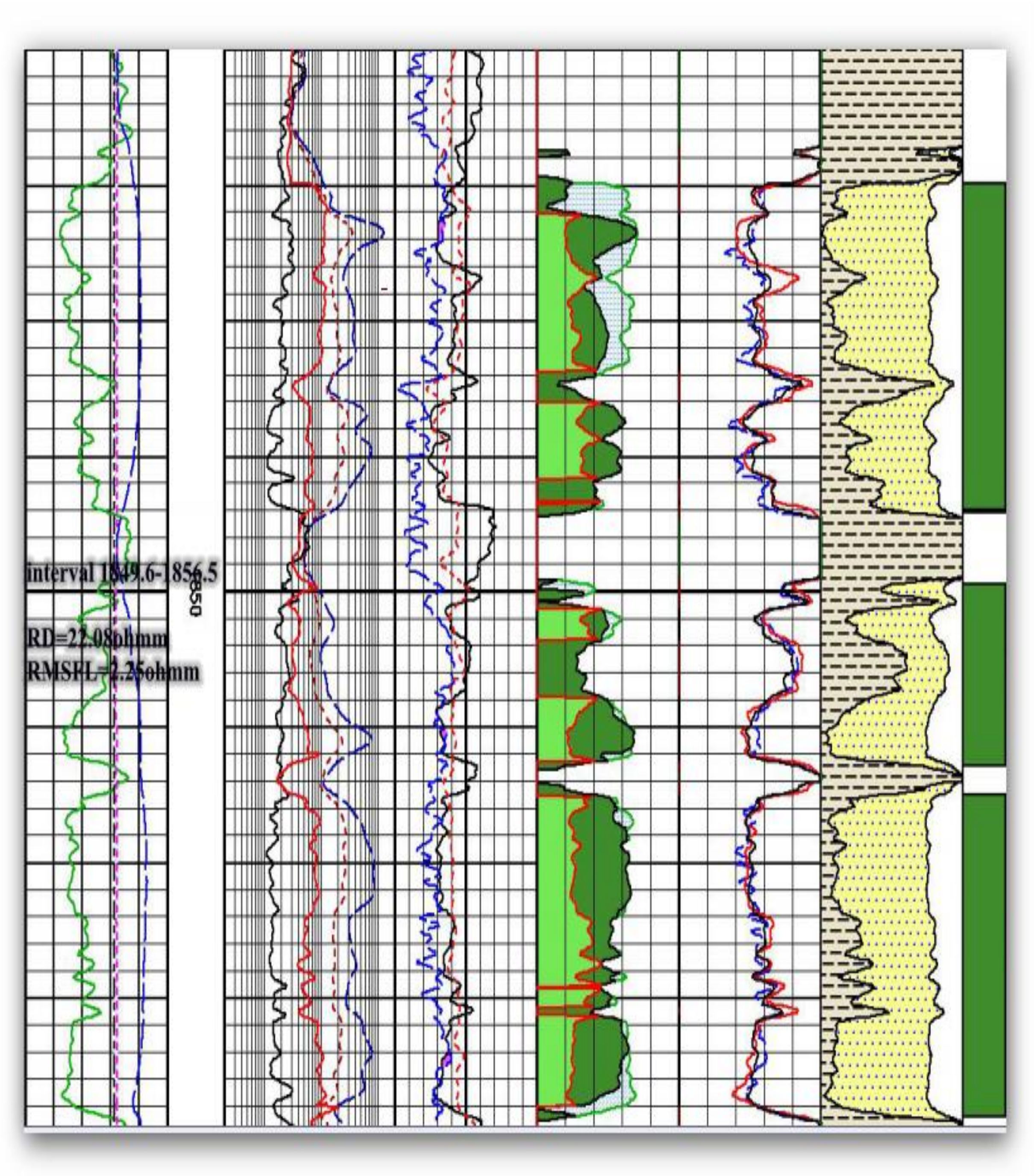

Fig. (4.7) Hadida N-8 well log

Interval 3094.47-3119.7

RD =15-16 ohm.m

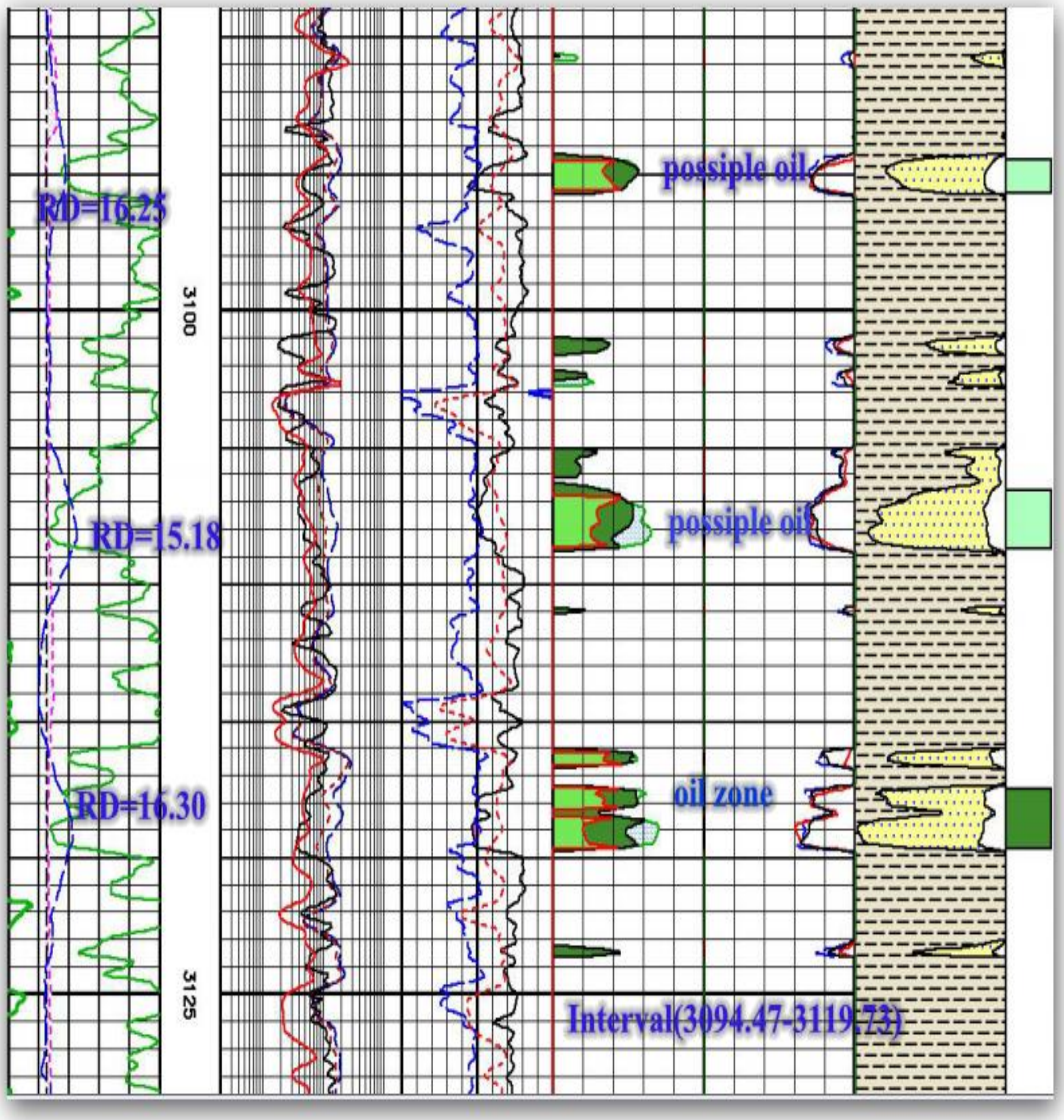

Fig. (4.8) Hadida well log Interval 3094.47-3119.7

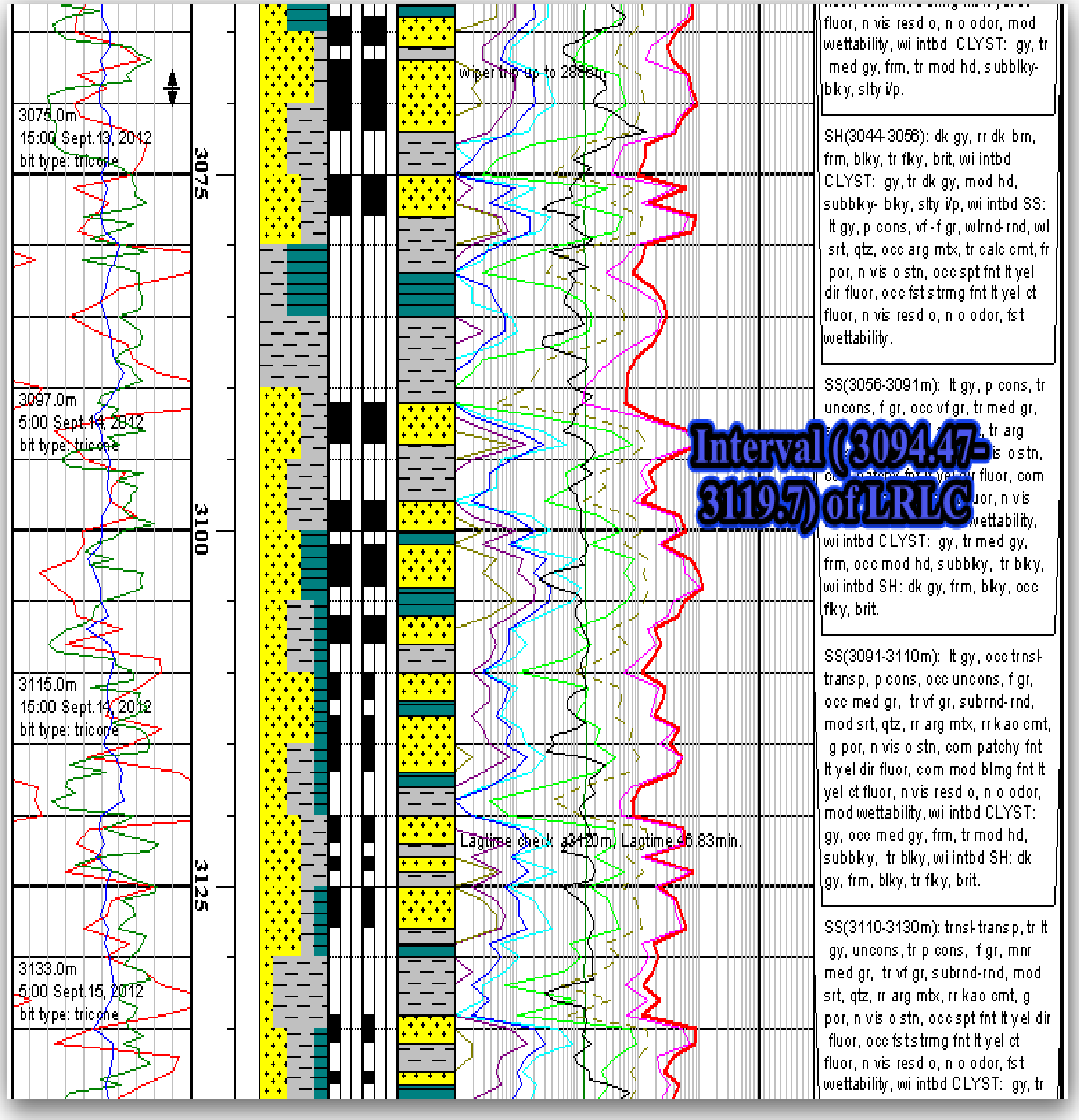

Fig. (4.9) Hadida N-8well log Abu Gabra Formation (Neocomian)

4.2.2 Cutoff Summary

Table (4.1) Hadida N-8 (625.0 – 3224.7m) Net Pay Cutoffs

Hadida N-8 (625.0 – 3224.7m) Net Pay Cutoffs: (MIN Pore: 14%, MAX Vsh: 50%, MIN SW:50% for Bentiu& Aradeiba MIN Pore: 10% for Abu Gabra)																			
Reservoir Pay								**Net Pay**											
No.	**Interval (m)**			**Thick (m)**	**Pore*h**	**AVG PORE (%)**	**AVG VSH (%)**	**Interval (m)**			**Thick (m)**	**Pore*h**	**AVG PORE (%)**	**Perm*h**	**AVG PERM (mD)**	**SW*h**	**AVG SW (%)**	**AVG VSH (%)**	**RESULT**
6	1835.01	-	1847.11	12.1	253.01	20.91	22.05	1835.02	-	1847.10	12.08	252.71	20.92	1214.54	100.54	594.34	49.2	22.02	oil
7	1849.49	-	1856.51	7.02	119.62	17.04	36.55	1849.65	-	1856.50	6.85	116.72	17.04	181.34	26.47	342.64	50.02	36.54	oil
8	1857.58	-	1869.21	11.63	260.63	22.41	16.89	1857.58	-	1869.19	11.61	260.30	22.42	1887.46	162.57	515.83	44.43	16.87	oil
16	1958.69	-	1965.54	6.85	133.301	19.46	31.04	1958.70	-	1965.54	6.84	133.11	19.46	308.95	45.17	340.97	49.85	31.02	oil
Total/Average Oil (Bentiu Formation)											**37.38**	**762.84**	**20.41**	**3592.29**	**96.10**	**1793.78**	**47.99**	**24.73**	
109	2699.89	-	2703.1	3.23	56.59	17.52	16.10	2699.93	-	2703	3.08	54.70	17.76	134.43	43.64	153.85	49.95	16.10	oil
110	2710.36	-	2712.4	2.00	32.86	16.43	15.73	2710.37	-	2712.4	1.99	33.71	16.94	66.23	33.28	99.68	50.09	15.72	oil
131	2941.47	-	2945.2	3.71	49.86	13.44	27.06	2941.47	-	2945.1	3.66	49.59	13.55	36.04	9.85	185.05	50.56	27.05	oil
132	2946.24	-	2947.1	0.84	10.91	12.99	25.01	2946.24	-	2947.1	0.84	10.91	12.99	7.39	8.80	42.18	50.22	24.99	oil
135	2977.28	-	2979.3	2.00	26.74	13.37	22.20	2977.3	-	2979.3	1.99	26.61	13.37	21.96	11.03	99.50	50.00	22.19	oil
136	2994.45	-	2996.5	2.01	25.75	12.81	22.70	2994.44	-	2996.5	2.01	25.81	12.84	18.11	9.01	100.58	50.04	22.7	oil
137	3028.56	-	3029.8	1.24	17.20	13.87	36.35	3028.56	-	3029.79	1.23	17.07	13.88	10.97	8.92	61.51	50.01	36.34	oil
138	3043.01	-	3043.9	0.92	13.27	14.42	24.54	3043.01	-	3043.9	0.91	13.15	14.45	16.62	18.26	41.47	45.57	24.50	oil
139	3061.13	-	3063.4	2.31	40.70	17.62	15.24	3061.15	-	3063.4	2.27	40.07	17.65	104.44	46.01	101.40	44.67	15.22	oil
140	3063.98	-	3065.7	1.69	28.83	17.06	20.13	3063.99	-	3065.7	1.68	28.69	17.08	57.56	34.26	82.42	49.06	20.14	oil
141	3068.99	-	3073.9	4.92	65.98	13.41	16.16	3069.00	-	3073.9	4.91	65.84	13.41	65.95	13.43	245.75	50.05	16.15	oil
144	3117.49	-	3119.7	2.24	27.80	12.41	27.19	3117.5	-	3119.7	2.20	27.39	12.45	15.20	6.91	109.30	49.68	27.19	oil
145	3139.36	-	3140.5	1.09	11.47	10.52	28.46	3139.37	-	3140.5	1.08	11.37	10.53	3.49	3.23	54.06	50.06	28.46	oil
146	3154.76	-	3158.6	3.85	38.35	9.96	28.32	3154.76	-	3158.6	3.82	38.20	10.00	9.73	2.55	191.31	50.08	28.30	oil
147	3162.5	-	3163.4	0.91	19.26	21.16	17.77	3162.60		3163.40	0.8	16.94	21.18	98.47	123.08	32.56	40.70	17.75	oil
Total/Average Oil (Abu Gabra Formation)											**32.47**	**460.06**	**14.17**	**666.57**	**20.53**	**1600.61**	**49.30**	**22.12**	

4.3 Low resistivity pay zone in Hadida N-2:

- Interval of LRLC in Hadida N-2 (1948.5-1952.6)
- RD =11-15ohm.m

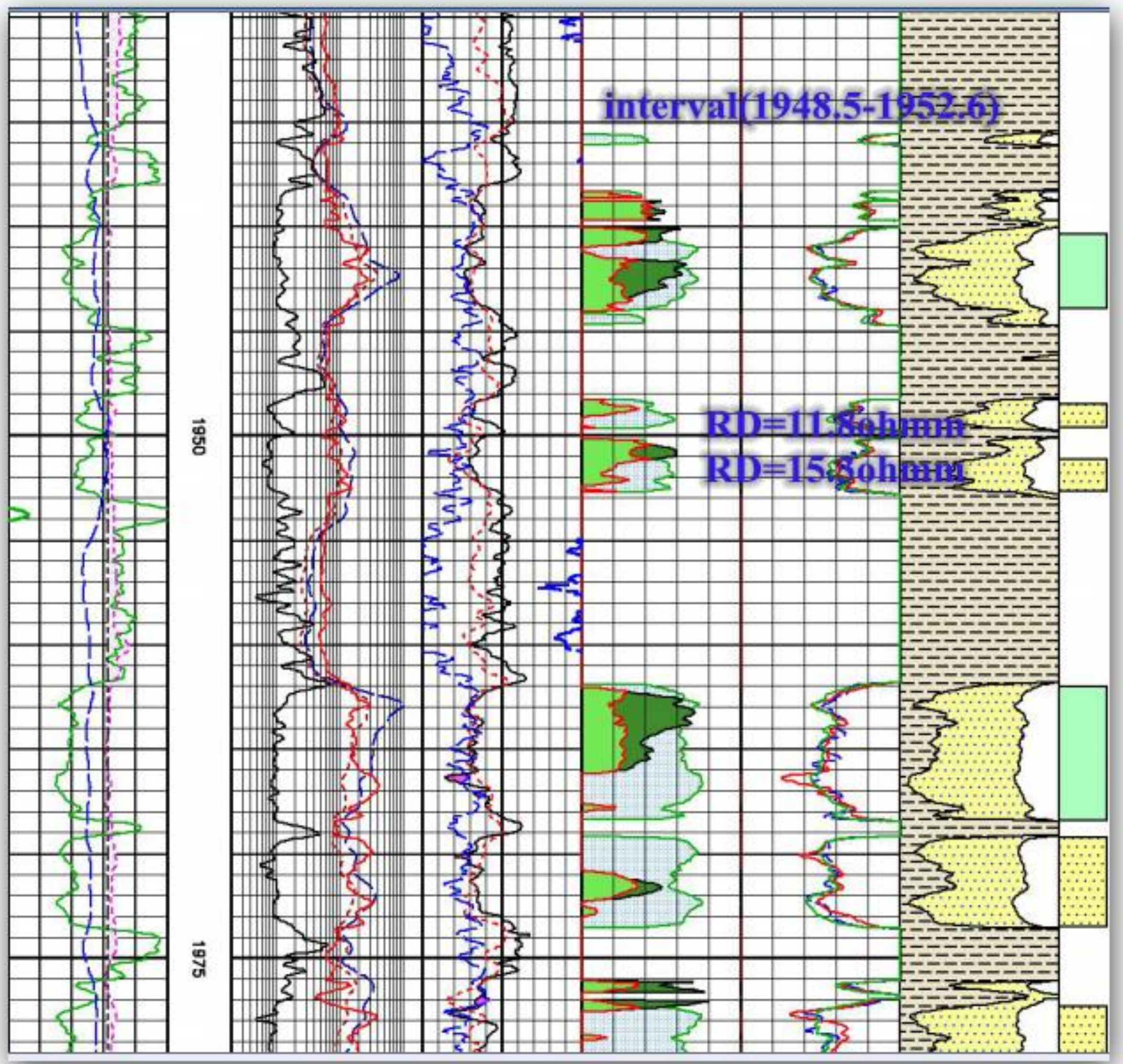

Fig. (4.10) interval of LRLC in Hadida N-2 (1948.5-1952.6).

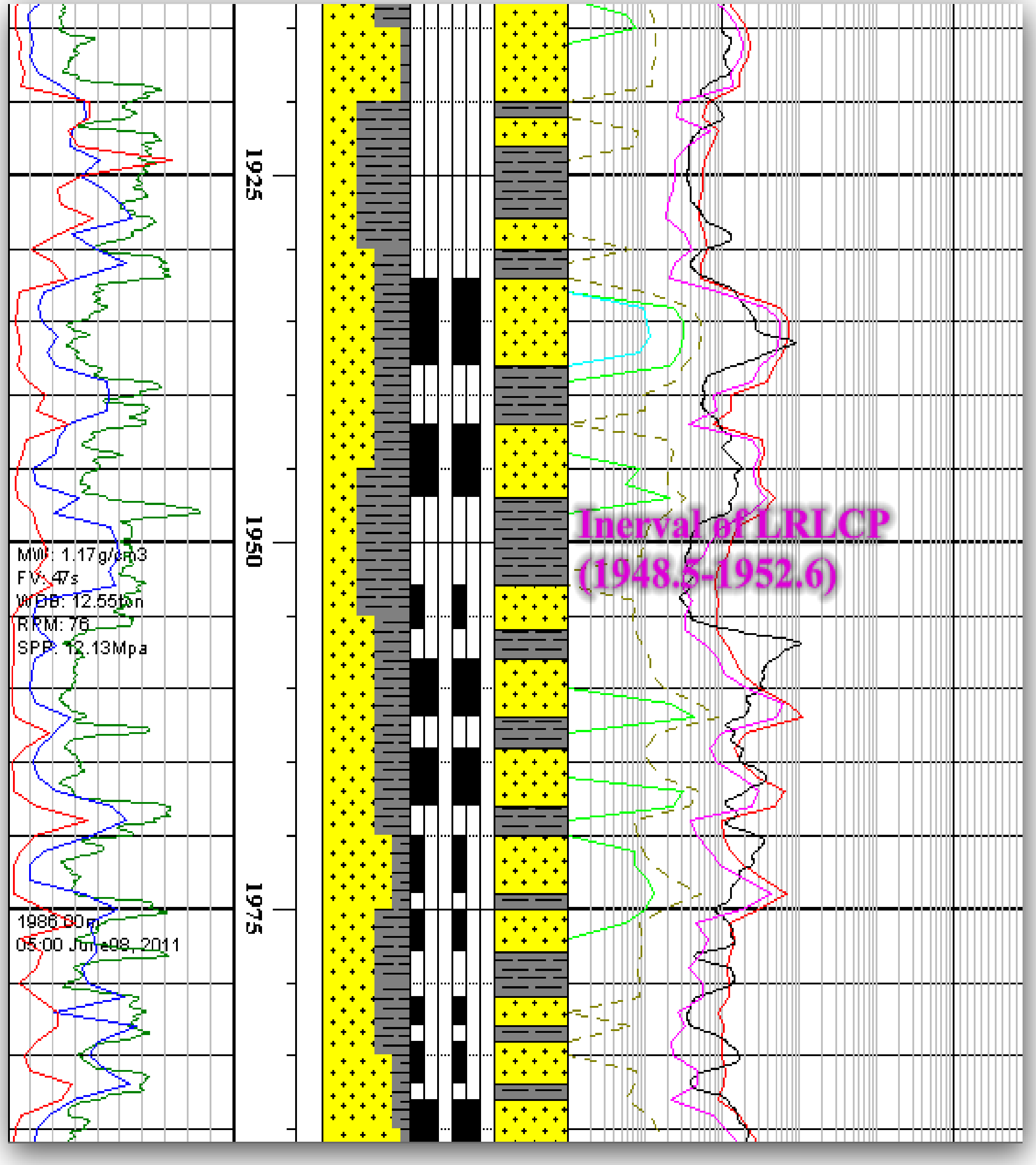

Fig. (4.11) Master log for Hadida N-2 for the interval of LRLC (1948.5-1952.6).

4.3.1 Cutoff summary

Table (4.2)Hadida N-2 (525.5-3250.0m) Net Pay Cutoffs

Hadida N-2 (525.5-3250.0m) Net Pay Cutoffs: (MIN Pore: 17%, MAX Vsh: 50%, MIN SW:50% for Bentiu, MIN Pore: 12% for Abu Gabra)																			
Reservoir Pay								**Net Pay**											
No.	**Interval (m)**			**Thick (m)**	**Pore*h**	**AVG PORE (%)**	**AVG VSH (%)**	**Interval (m)**			**Thick (m)**	**Pore*h**	**AVG PORE (%)**	**Perm*h**	**AVG PERM (mD)**	**SW*h**	**AVG SW (%)**	**AVG VSH (%)**	**RESULT**
1	1791.0	-	1795.4	4.4	93.3	21.2	21.0	1791.0	-	1795.4	4.4	93.3	21.2	673.1	153.0	176.2	40.1	21.0	oil
2	1805.3	-	1807.9	2.6	45.8	17.8	23.7	1805.3	-	1807.9	2.6	45.8	17.8	176.7	68.5	110.8	43.0	23.7	oil
3	1808.8	-	1822.9	14.1	307.7	21.8	15.7	1808.8	-	1822.9	14.1	307.7	21.8	4656.8	329.3	436.1	30.8	15.7	oil
Total/Average Oil (Bentiu Formation)											**21.1**	**446.8**	**21.2**	**5506.6**	**260.7**	**723.1**	**34.2**	**17.8**	
4	1826.3	-	1835.8	9.5	214.0	22.5	16.9	1826.3	-	1835.8	9.5	214.0	22.5	3035.3	319.2	470.7	49.5	16.9	oil
6	1848.3	-	1852.1	3.8	74.6	19.6	19.5	1848.3	-	1852.1	3.8	74.6	19.6	608.8	159.8	169.2	44.4	19.5	oil
15	1940.4	-	1943.9	3.5	79.0	22.6	24.9	1940.4	-	1943.9	3.5	79.0	22.6	704.8	201.9	213.1	61.1	24.9	oil
18	1962.0	-	1968.3	6.3	145.1	23.0	21.5	1962.0	-	1968.3	6.3	145.1	23.0	1579.1	250.3	432.6	68.6	21.5	oil
Total/Average Possible Oil (Bentiu Formation)											**23.1**	**512.7**	**22.2**	**5928.1**	**256.4**	**1285.7**	**55.6**	**19.8**	
171	2948.8	-	2949.8	1.0	18.1	18.3	17.6	2948.8	-	2949.8	1.0	18.1	18.3	55.5	56.1	49.2	49.7	17.6	oil
172	2950.7	-	2952.2	1.5	28.5	19.0	24.4	2950.7	-	2952.2	1.5	28.5	19.0	138.3	92.2	56.0	37.3	24.4	oil
174	2960.4	-	2961.8	1.4	27.4	19.0	21.8	2960.4	-	2961.8	1.4	27.4	19.0	81.5	56.6	71.6	49.8	21.8	oil
Total/Average Oil (Abu Gabra Formation)											**3.9**	**74.1**	**18.8**	**275.4**	**70.1**	**176.9**	**45.0**	**21.9**	
168	2908.9	-	2911.2	2.3	32.1	14.1	35.3	2908.9	-	2911.2	2.3	32.1	14.1	30.7	13.5	126.9	55.7	35.3	possible oil
177	2988.5	-	2989.7	1.2	21.1	17.3	6.5	2988.5	-	2989.7	1.2	21.1	17.3	48.9	40.1	63.5	52.0	6.5	possible oil
178	3019.5	-	3021.4	1.9	28.0	14.7	32.4	3019.5	-	3021.4	1.9	28.0	14.7	32.3	17.0	100.5	52.9	32.4	possible oil
179	3039.9	-	3042.5	2.6	38.8	15.0	25.8	3039.9	-	3042.5	2.6	38.8	15.0	45.8	17.7	141.4	54.6	25.8	possible oil
180	3045.7	-	3046.7	1.0	16.2	16.4	24.1	3045.7	-	3046.7	1.0	16.2	16.4	29.1	29.4	49.6	50.1	24.1	possible oil
181	3047.4	-	3048.1	0.7	13.2	19.2	16.7	3047.4	-	3048.1	0.7	13.2	19.2	49.3	71.5	37.2	53.9	16.7	possible oil
194	3172.5	-	3175.3	2.8	46.9	17.1	24.1	3172.5	-	3175.3	2.8	46.9	17.1	108.1	39.3	147.9	53.8	24.1	possible oil
Total/Average Possible Oil (Abu Gabra Formation)											**12.4**	**196.3**	**15.8**	**344.2**	**27.7**	**666.9**	**53.7**	**25.7**	