FORMATION EVALUATION WITH HIGH RESOLUTION LOGGING IN SELECTED NIGER DELTA WELLS

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ABSTRACT

Field trial with the Magnetic Pulse Inc. (MPI) Extended Range High Resolution tool (XHR) is currently ongoing in some major oil Companies of Nigeria. Objectives of the trials are to ascertain the overall performance of the tool and its applicability in the Niger Delta sandstone area when compared to conventional resistivity logs. The XHR is an induction tool which uses pulsed power to provide the source electromagnetic fields. The pulsed source of the XHR generates power bursts exceeding 20 million watts, compared to the steady sinusoidal source flew of about 150 watts produced by conventional induction tools. Its high power, extended transmitter-to-receiver spacing and the data processing by an entirely new, sophisticated inversion algorithm are the special features which give it a claim to deep investigation and high vertical resolution superior to conventional induction and later log tools. To date the XHR has been logged in three wells in xyz companies (one vertical and Iwo deviated with deviation ranging between 20 to 30 degrees). Preliminary results from field tests show that MPI's claim that the tool can resolve 1 foot layers is tenable. Using Shell proprietary resistivity tool modeling software, One was able to verify that the XHR gave a good representation of formation resistivity. Comparison of hydrocarbon saturations estimated from both XHR and Dual laterolog resistivities indicate that evaluations in laminated sand/shale sequences using the laterolog can be pessimistic. As such sequences are abundant in the Niger Delta, the application of modern XHR logging technology offers scope for increasing reserves and hydrocarbon in place estimates in some Nigerian oil and gas reservoirs/fields. Despite the encouraging results, the XHR also has some shortcomings. An artefact of the tool is occasional high resistivity spikes. In addition, the tool response in some clean hydrocarbon sands shows reduced resistivity readings which are yet to be adequately explained. More trials are still planned.

Keywords ; *Logs , Deviated well , Sand , Shale , Hydrocarbon, Reserves, Resistivity, Pulse, Laterlogs, Saturation , Induction tools, Niger delta sandstone, and clean formation*

INTRODUCTION

MPI's (Magnetic Pulse mc) Extended Range High Resolution Induction tool (XHR) was introduced into the oil and gas industry in August 2017. To date, the tool has been run in three wells. The objectives of the field trials are to ascertain the overall performance of the tool and its applicability in the Niger Delta area when compared to conventional resistivity tools.The XHR is an induction type tool which consists of a transmitter coil and two antenna assemblies located about 9 feet below the transmitter (see figure 1). Each antenna assembly has 4 receivers with spacing's of about 3 inches. The tool uses pulsed power to provide the source electromagnetic fields. The pulsed source of the XHR generates power bursts exceeding 20 million watts (lasting for 1 millisecond per foot), compared to the steady sinusoidal source field of about 150 watts of conventional induction tools. Enhanced vertical resolution is achieved through the small receiver antenna spacing while the extended transmitter/receiver spacing gives the tool a greater depth of investigation in contrast to conventional resistivity tools. The electromagnetic fields recorded by the receiver coils are processed by an entirely new sophisticated inversion algorithm. The inversion processing is based on a model in which the formation is made up of horizontal layers with thicknesses in increments of one foot. Frank [4]

Though the field trials are still ongoing, preliminary results from the tests are presented here. True formation resistivity computed from conventional DLL,Rxo logs were compared with the XHR. Also attempts were made to verify the formation resistivity from the XHR using Shell proprietary resistivity modeling software.Woodhouse [7]

DATA ACQUISITION

The XHR was logged in three onshore wells. The details of each well are as follows:

WELL-1

Well-1 was a deviated appraisal/development well. The mud type in use was KCL polymer for the 12 1/4" and 8 1/2" hole sections. Maximum hole deviation was 30 degrees. Both the 12 1/4" and 8 1/2" hole sections were logged with conventional resistivity (DLL / MILL / SP / GR / CAL) by Atlas Wire line Services (AWS). MN's XHR was logged using AWS's cable after logging the conventional resistivity tools and density/neutron logs. The XHR was successfully logged in both hole sections.

WELL-2

Well-2 was a deviated development well drilled from the same cellar as well-i. The maximum hole deviation was 28 degrees. The 8 1/2" hole section was drilled using KCL polymer mud. Conventional resistivity (DLL I MILL I SP / GR / CAL) and density/neutron logging was done by AWS. Like in well-i, the XHR was successfully logged using AWS's cable.

WELL-3

This was a vertical development well from a different field. The mud type used was KCL polymer. Conventional resistivity (DLL / MSFL / SP / GR / CAL) and density/neutron logging was done by Schlumberger. The XHR was logged using Schlumberger's cable.

During the tests in the above three wells, no tool failures were recorded. Total hours in hole was 27.0 hours.

DATA INTERPRETATION / RESULTS

A comparison of environmentally corrected conventional resistivity logs was made with the XF{R logs. In an attempt to highlight differences in absolute tool readings, composite depth plots of both the conventional resistivity and XHR logs were made. Whiteman [8] Histograms and cross plots were also made to establish differences in the distribution of the XHR and the conventional resistivity logs from the same intervals. Moreover, using the XHR data as a representation of true formation resistivity (Rt), a laterolog deep(shallow response was modeled and subsequently compared to the actual laterolog provided by conventional resistivity tools.

LOG QUALITY

The repeatability of the tool was checked and found to be good (See figure 2). However, some differences in absolute values are discernable. This is primarily due to poor repeat depth indexing which is a unique aspect of pulsed power resistivity logging. Anderson [9.] At one pulse per foot, the XHR tool gives a resistivity averaged over one foot. Therefore, if during repeat logging the tool is not hoisted to exactly the same depth, this average will be derived from a different depth interval. This behaviour is however considered acceptable when compared to other resistivity tools.

An enhancement to the XHR log is the reprocessing that corrects for dips. Figures 3 and 4 show depth plots of XHR and dip corrected XHR (XHR_DCX) from well-i and well-3 respectively. Barber [10.] Some increase can be observed in the XHR DCX from well-i while there are no discernable differences in both logs from well-3. Dip angles as high as 10-20 degrees were encountered in well-i while the maximum dip angle in well-3 was 4.5 degrees. Hence, significant improvements are expected from reprocessing of XHR acquired from high angle dipping beds.

a. HYDROCARBON DETECTION

Hydrocarbon detection using the XHR log is comparable to the conventional resistivity logs. The XHR shows drop off features at hydrocarbon water contacts as expected. All hydrocarbon bearing intervals identified on the laterolog were also picked by the XHR.

1 *Clean Hydrocarbon Bearing Zones*

Comparison of hydrocarbon saturation estimates using both the XHR and LU shows negligible differences in this type of zones as shown in Figure 5. However, in certain clean hydrocarbon bearing zones the saturation estimates from the XHR are significantly lower than that from the LLd (See Figure 6 and Table 1). These reductions are not correlatable to fluid type, lithology or hole conditions. The probable cause of this phenomenon is yet to be explained but is expected to be related to the different depths of investigation of the XHR and LU. Anderson [11].

2 *Shaly Hydrocarbon Bearing tones*

Depth plots of XHR and Rt from LU and micro resistivity for shaly and laminated intervals are shown in Figures 7 and 8. Considerable shale laminations shown on the micro resistivity and dip meter can be picked on the XHR. Hydrocarbon saturation computed using the XHR is higher than that obtained using RI from LLd and Rxo by some 3 to 18 percent (Table 2). Also an increase in the equivalent hydrocarbon column (EHC) as high as 70 percent is obtainable.

3. *Variation In Hydrocarbon Saturation With Resistivity*

The variation in hydrocarbon saturation with changes in resistivity values was investigated. A composite cross plot of resistivity from the laterolog and hydrocarbon saturation from both the XHR and Lid was made (Figure 9). At resistivities greater than 300 ohmm, the hydrocarbon saturation estimates from both XHR and LU show negligible differences Kennedy [14] .However at low resistivities (<300 ohmm) hydrocarbon saturations from the XHR are generally higher.

b. *LOW RESISTIVITY (NON HYDROCARBON) ZONES*

In shales and saline water bearing formations the XHR gives consistently lower readings than the LU (Figure 10). A comparison of Rw obtained from LU, XHR and produced water (Table 3) shows that the XHR gives a more representative Rw. This is expected, as the XHR is an induction tool.

d. *FRESH WATER ENVIRONMENT*

Figures 11, 12 and 13 show depth plots of XHR/LLd logs taken in the fresh water environment of well 1,2 and 3, respectively. The diameter of invasion ranges between 30 to 45 inches. The mud properties across these intervals .are presented in Table 4. It can be observed in figure 11 that the XHR is consistently lower than the LU with occasional spikes on the XHR. Figure 13 shows erratic behaviour on the) CHR while in Figure 12 the XHR is slightly higher than LU. Examination of the mud properties shows that Well-3 has a more saline mud. The erratic behaviour of the XHR from Well-3 may be attributable to the mud salinity. Sheali [12]

e. *RESISTIVITY MODELLING*

An attempt to verify the resistivity reading from the XHR necessitated a laterolog resistivity modeling exercise. The XHR data was used as a representation of the true formation resistivity from which a laterolog deep/shallow response was modeled using Shell proprietary resistivity modeling software. Generally there was a good fit between the modeled resistivity curve and the actual LU data (Figure 14). For high resistivities (>100 ohmm) or when the XHR reads far lower than the LU (section 3.2.1) the fit between the modeled and actual laterolog is poor. Spalburg [13]

COST CONSIDERATION

Differences in cost btw the XHR and conventional resistivity were compared. The rig time cost was also considered in both cases. The cost analysis showed that the XHR costs about twice the price of conventional resistivity logs.

DISCUSSION

The XHR log has proved be reliable in thin bed detection and enhanced logging in laminated sand/shale sequences from the wells so far logged in SPDC. MPI’s claim that the tool can achieve 12 feet depth of investigation could not be confirmed considering the invasion diameters of 30 to 45 inches that were encountered.

The fresh water environments of the Niger Delta area are characterized by high resistivities which are similar to those obtained in hydrocarbon bearing intervals. Also, the formations are loose/under compacted and filtrate invasion is generally high. Hydrocarbon identification in these fresh water environments using the conventional resistivity/induction tools is quite cumbersome due to the limitation of these tools in terms of their depth of investigation. Considering the depth of investigation being claimed by MPI, the XHR may offer some scope for hydrocarbon identification in this environment. However, if the erratic phenomenon that was encountered in well-3 is a tool defect then the application of the tool in the fresh water environment of the Niger Delta may be elusive. Values of apparent resistivity measurements are not instantly available as in conventional resistivity logs. Two to four hours were spent on processing of resistivity data during the trials. This could result in delays in rig operations if only XHR logs are adopted as the resistivity tool in a well. The need to improve on the processing time is deemed necessary. In the interim, the XHR could be considered to complement conventional resistivity tools in cases where enhanced resistivity measurements are required, most especially in the laminated sequences with resistivities less than 300 ohmm where significant gains can be expected in EHC. Presently, the reprocessing of the) GIR log for dip corrections requires manual input from the dip meter log. Considering the possible increase in the hydrocarbon potential using the dip corrected XHR, the possibility of integrating a dip measuring device into the XHR tool string should be investigated by MPI as this will provide a good database for the processing of the XFIR.

CONCLUSIONS

i MPI’s claim that the XHR can resolve thin beds is tenable. The tool has a vertical resolution of one foot which is superior to that obtained from conventional resistivity tools.

ii Simulation of laterolog from XHR data indicated that the XHR is a good representation of true formation resistivity.

iii Due to the extensive computations that are involved in the inversion processing, immediate values of apparent resistivity are not available from XHR logs. For operational reasons the XHR therefore cannot be taken as a complete replacement of conventional resistivity logs but as an addition to current technology pending the availability of improved processing techniques.

iv Hydrocarbon saturation estimates from both the XHR and LLd show negligible differences in clean hydrocarbon bearing sands while in laminated sand/shale sequences the XHR gives higher saturation values. As a result, the application of the tool could be limited to laminated and low resistivity formations.

v High dip angle has significant impact on the XHR log. Hence reprocessing of XHR for dip correction is encouraged. Also, the possibility of integrating a dip measuring device unto the XHR tool string should be investigated by MPI.

vi Tool response in fresh water environment is still questionable. However, the XHR may offer some benefits in view of its depth of investigation.

vii An artefact of the tool is occasional high resistivity spikes

viii The tool also has occasional low resistivity readings in relatively well developed sand units. This phenomenon has not yet been adequately explained.

NOMENCLATURE

CAL = Caliper log
GR = Gamma Ray log
LLD = Laterolog Deep
LLS = Laterolog Shallow

MILL = Microlog
MSFL = Microsphericafly focused log
MOD_LLD = Modelled Laterolog Deep
MOD_LLS = Modelled Laterolog Shallow
Rt = True Formation Resistivity
RT_LLD = True Formation Resistivity from LLD
Rxo = Resistivity of flushed zone
SH = Hydrocarbon saturation
SH_LLD = Hydrocarbon saturation from LLD
SH_XHR = Hydrocabon saturation from XHR
SP = Spontaneous potential
SW_DCX = Water saturation from dip corrected XHR
SW_XHR = Water saturation from XHR not corrected for dip
XHR = Extended Range High Resolution Induction tool
XHR_L = XHR main log
XHR_R = XHR repeat log
XHR_DCX = XHR dip corrected

Table 1: Comparison of Hydrocarbon Saturation from Anomalous Zones

Well	**Interval**	**HC Saturation (%)**			**Equivalent HC Column**		
		LLd	XHR		LLd	XHR	
Well-1	6900-6942	80	66	14	9.53	7.49	-21
Well-1	6961-6988	57	44	13	4.70	3.05	-22
Well-1	7010-7033	65	50	15	431	3.27	-24
Well-1	7072-7132	44	36	8	7.23	5.24	-28

Table 2: Comparison of Hydrocarbon Saturation from XHR and LLd in shaly/laminated sands

Well	**Interval**	**HC Saturation (%)**			**Equivalent HC Column**		
		LLd	XHR		LLd	XHR	
Well-1	8560-8655	42	60	18	6.45	10.01	+55
Well-1	8672-8700	65	79	14	3.45	5.88	+70
Well-2	8030-8070	89	92	3	10.32	10.67	+4
Well-3	6900-7050	76	79	3	19.20	19.49	+ 2
Well-3	7060-7160	67	73	6	12.05	13.13	+10
Well-3	7180-7300	72	75	3	14.37	14.77	+ 3
Well-3	8050-8100	74	82	8	7.95	8.81	+11

Table 3: Comparison of Formation Water Resistivity’s (Rw)

XHR	LLd	Produced Water	
020	0.25	0.20	A
0.25	0.29	0.24	B

Table 4: Mud property

Well	interval	Rm	Rinf	Rmc	Temp	S.G.	Visc	Ph	Fluid Ioss cc
W-1	8497-4014	1.50	1.30	1.60	DegF	1.09	50	10.0	3.3
W-1	9477-8491	0.19	0.17	0.36	75	1.13	49	9.9	4.5
W-2	8511-5001	1.69	1.29	2.11	80	1.09	53	9.5	5.0
W-3	8577-5514	0.20	0.18	0.44	75	1.11	58	10.0	4.2

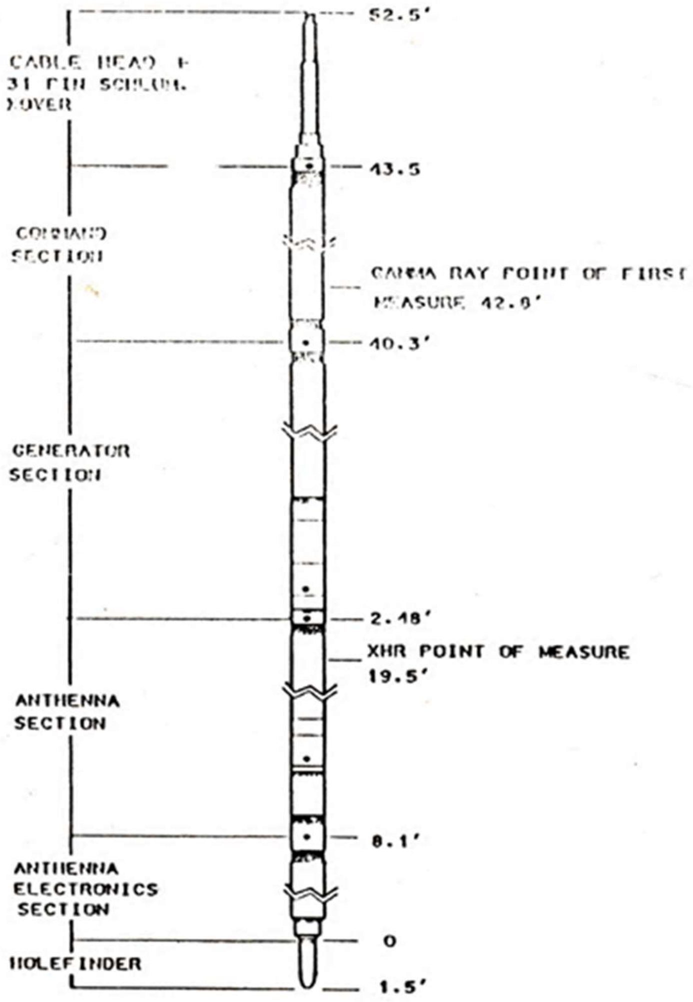
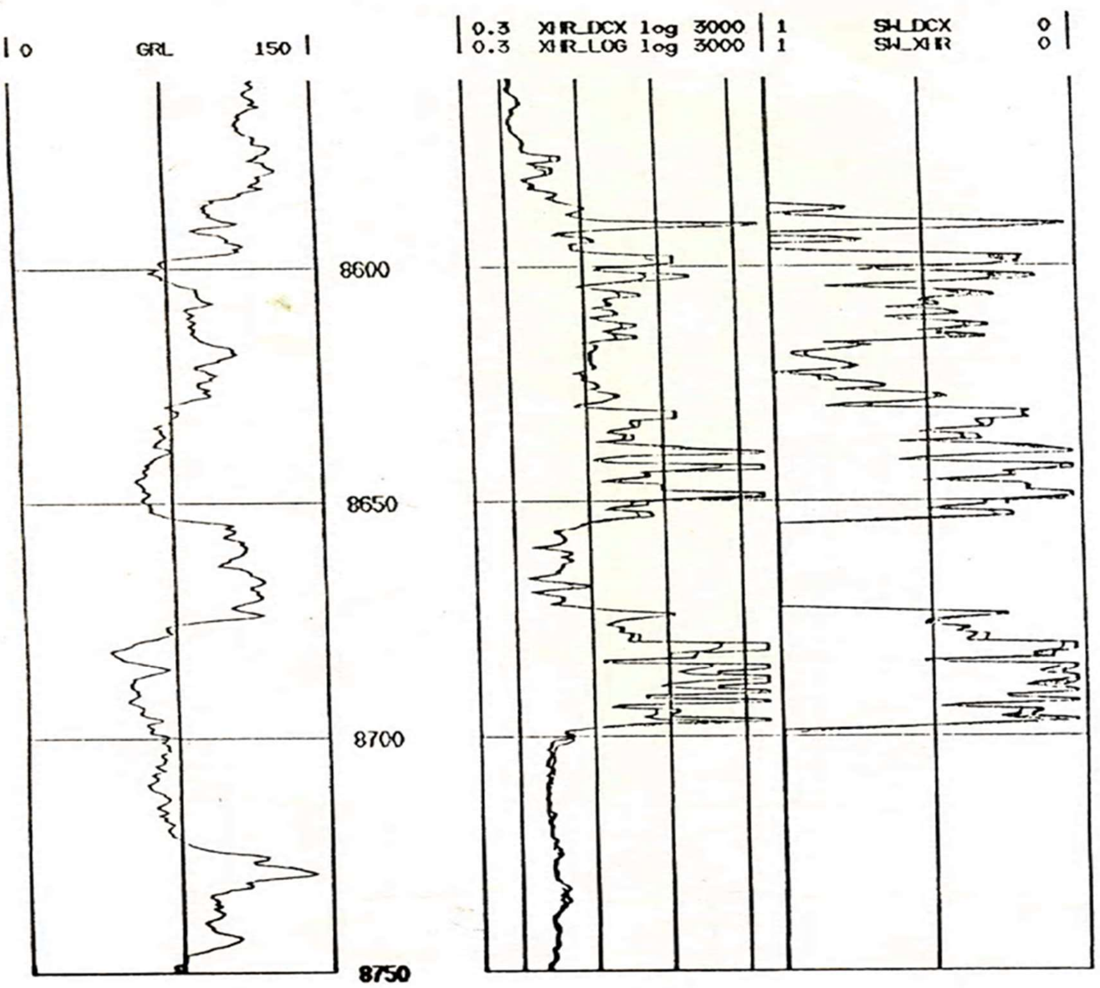
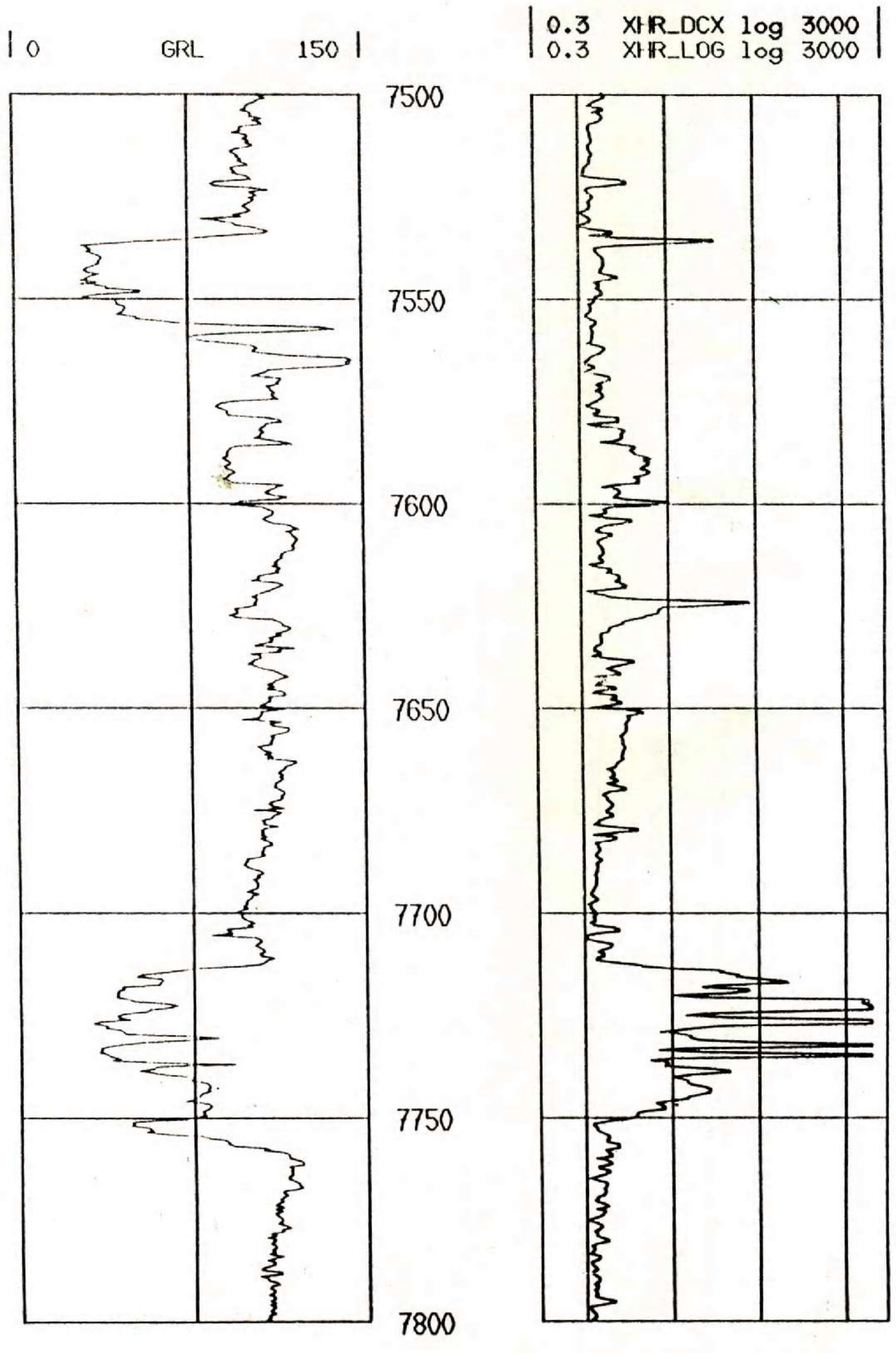


Figure1 : Log Repeatability check

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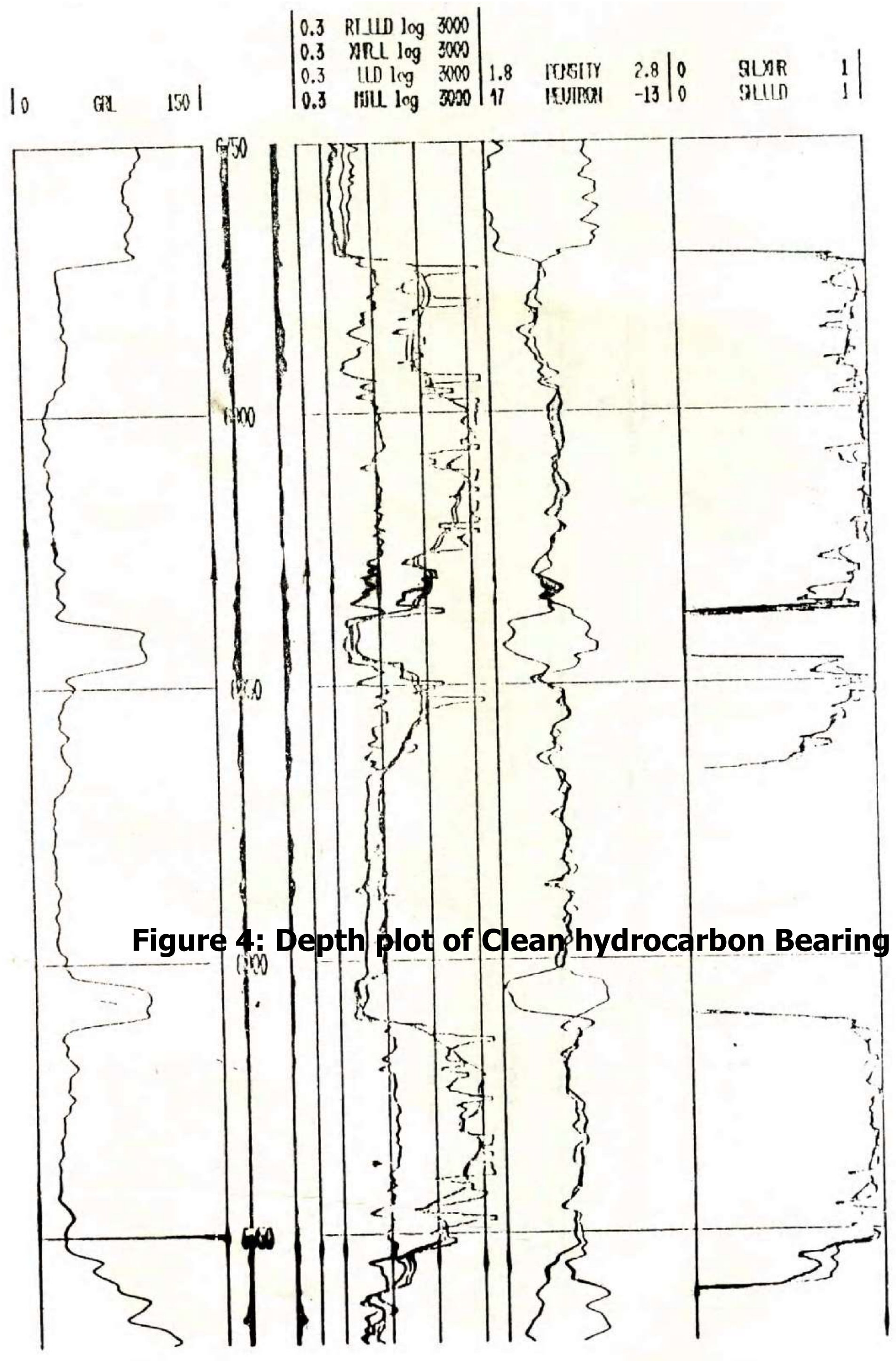
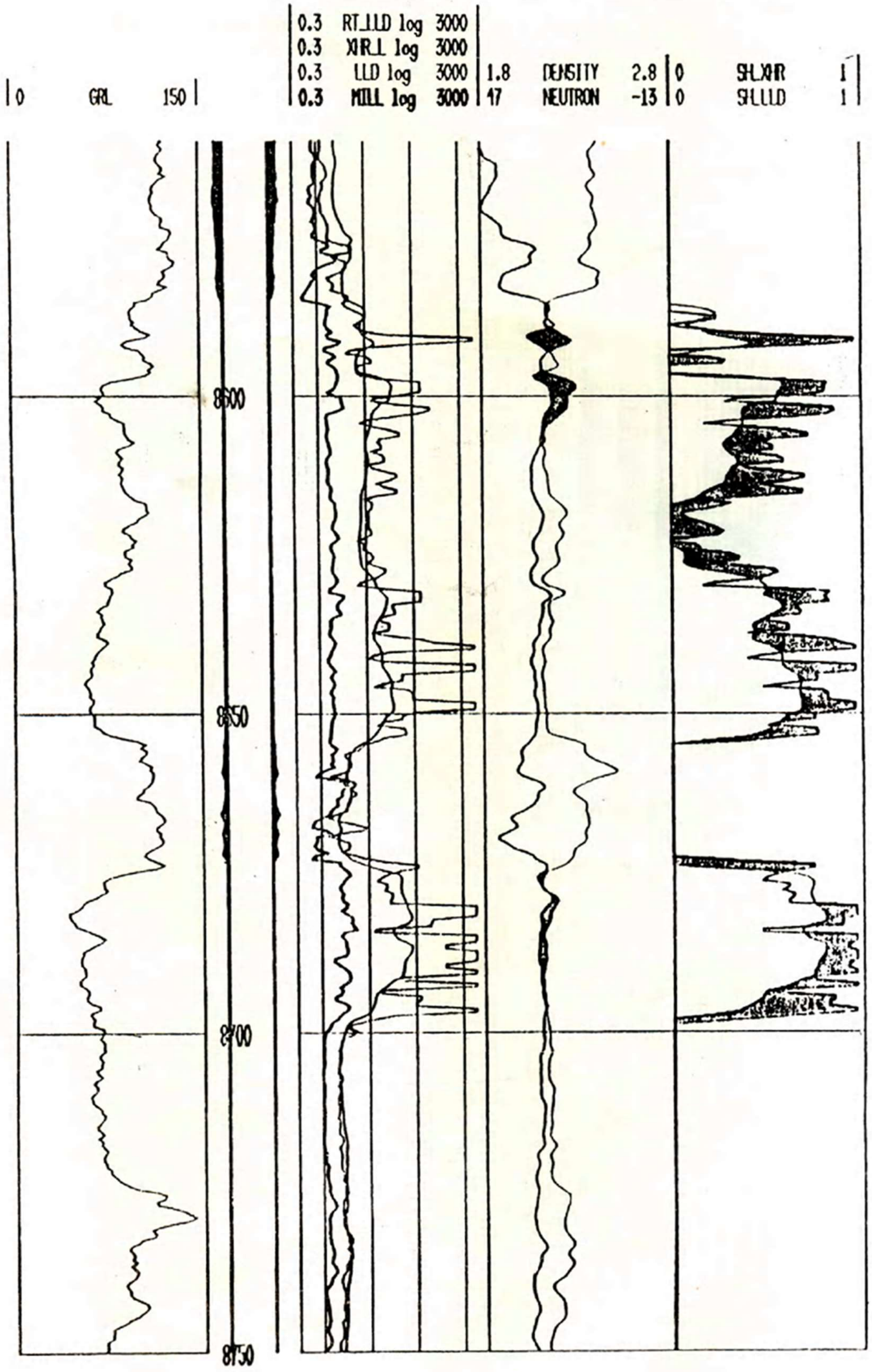


Figure 4: Depth plot of Clean hydrocarbon Bearing Zone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0 SH_LLD 1
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8650
8700
8750

Figure 7: Depth plot of Shaly Hydrocarbon Bearing Zones

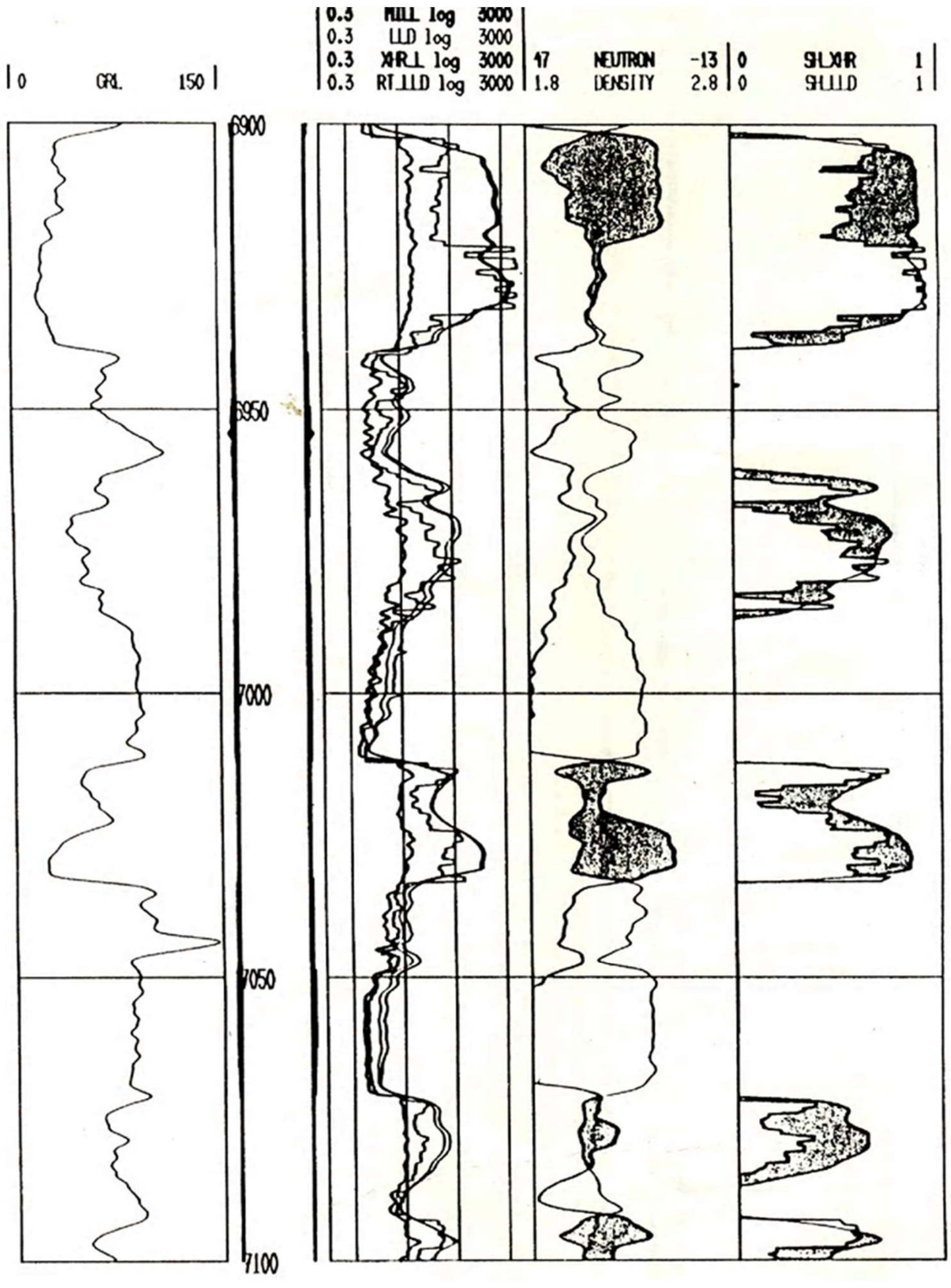
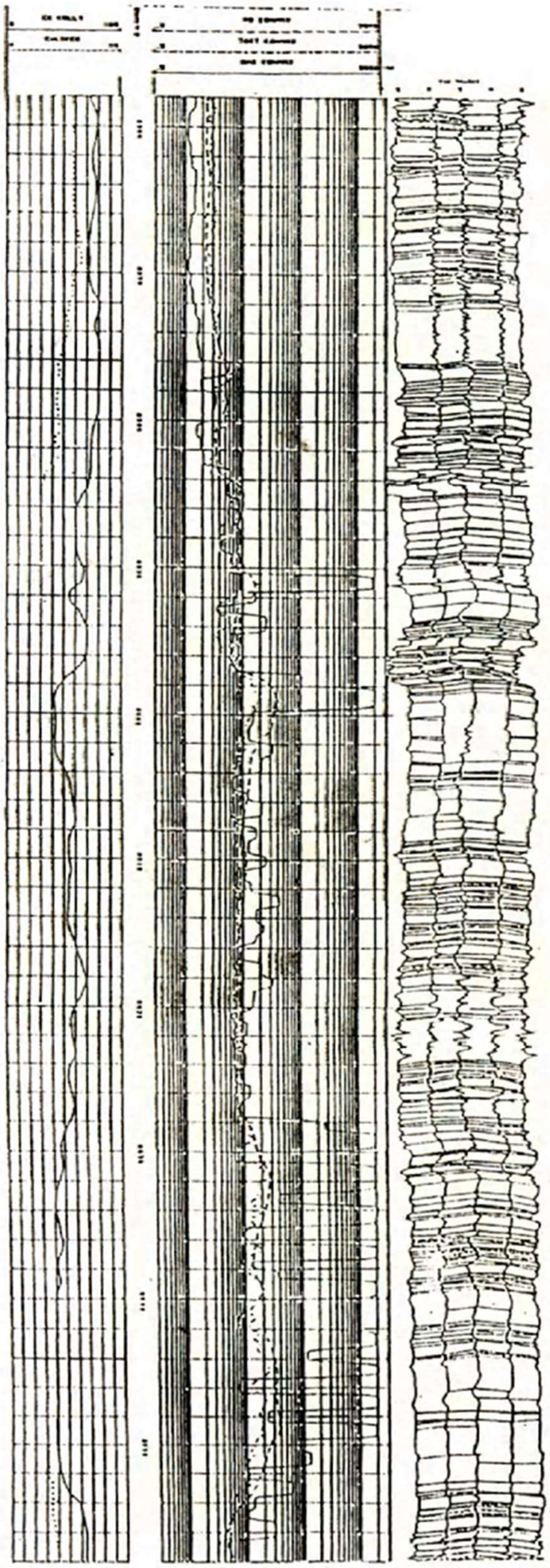


Figure5: Anomalous Behaviour In Clean Hydrocarbon Bearing Sands



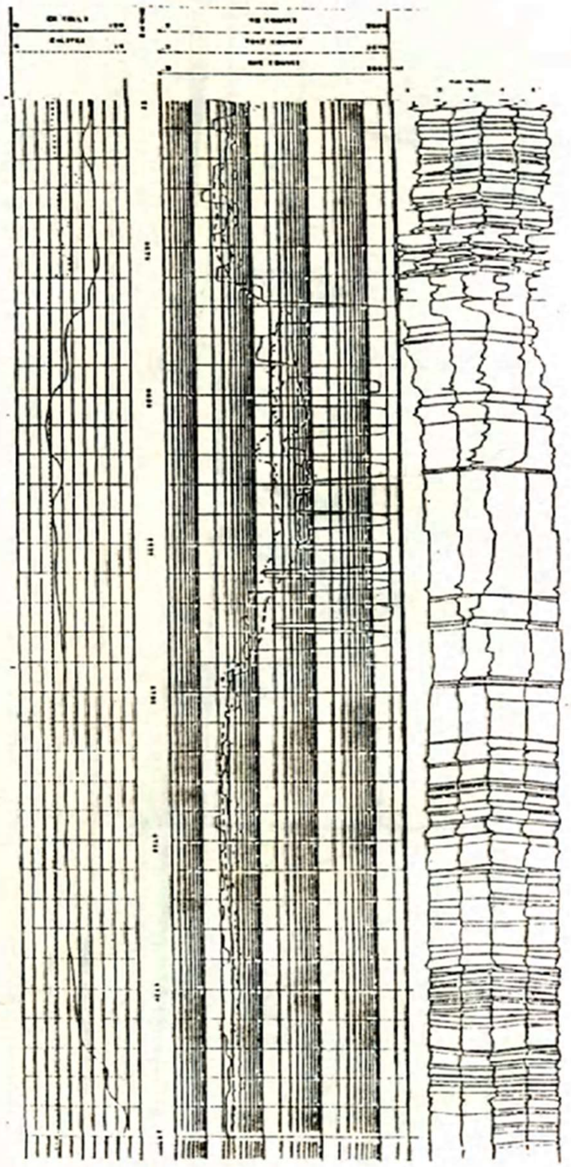
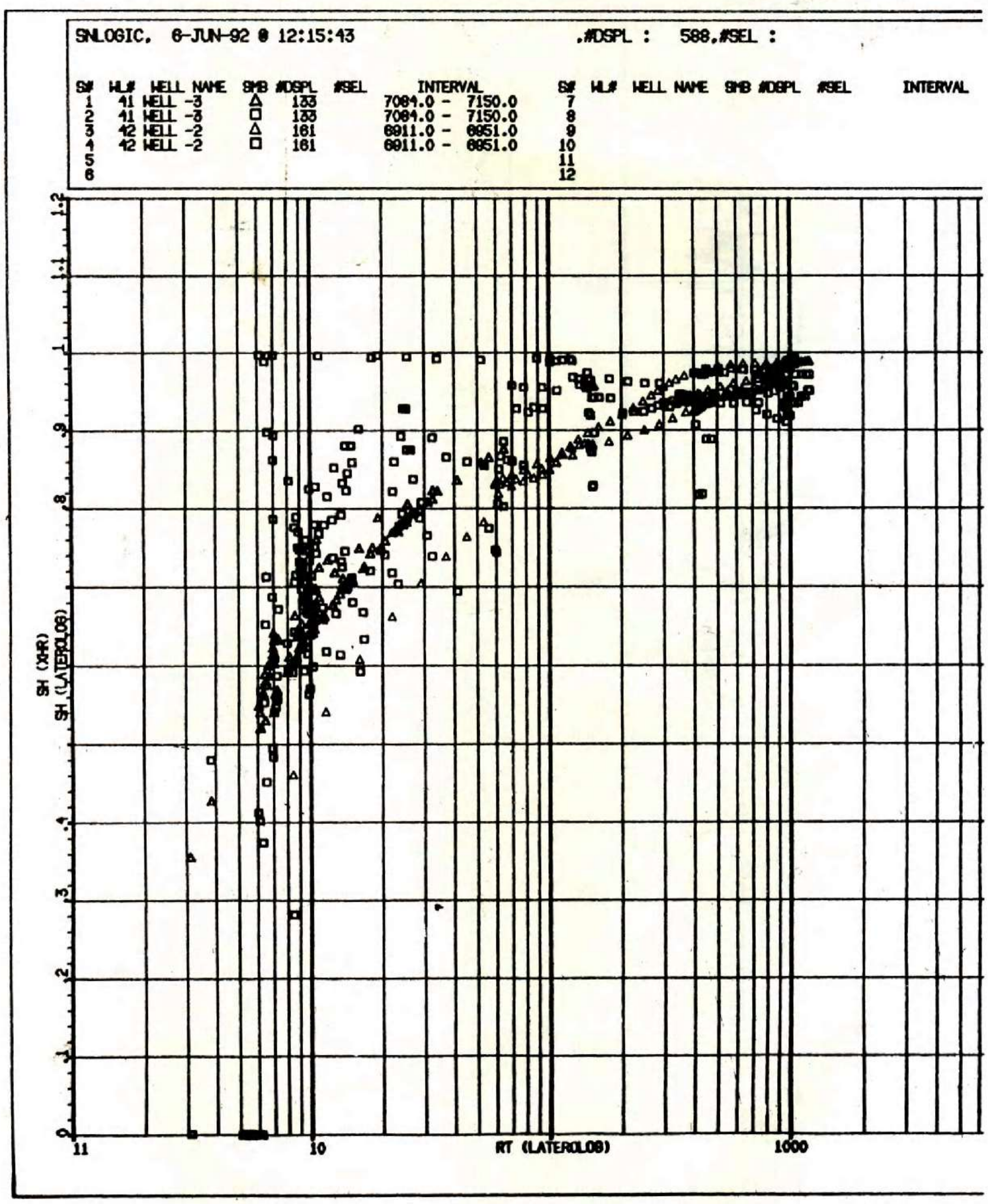


Figure 6: Overlay of XHR, LLd and TBRT (AWS Thin Bed Resistivity Tool) with Diameter

Sh from Laterolog
Sh from XHR



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 2   41  WELL -3      □    133          7084.0 -  7150.0      8
 3   42  WELL -2      △    161          6911.0 -  6951.0      9
 4   42  WELL -2      □    161          6911.0 -  6951.0     10
 5                                                           11
 6                                                           12
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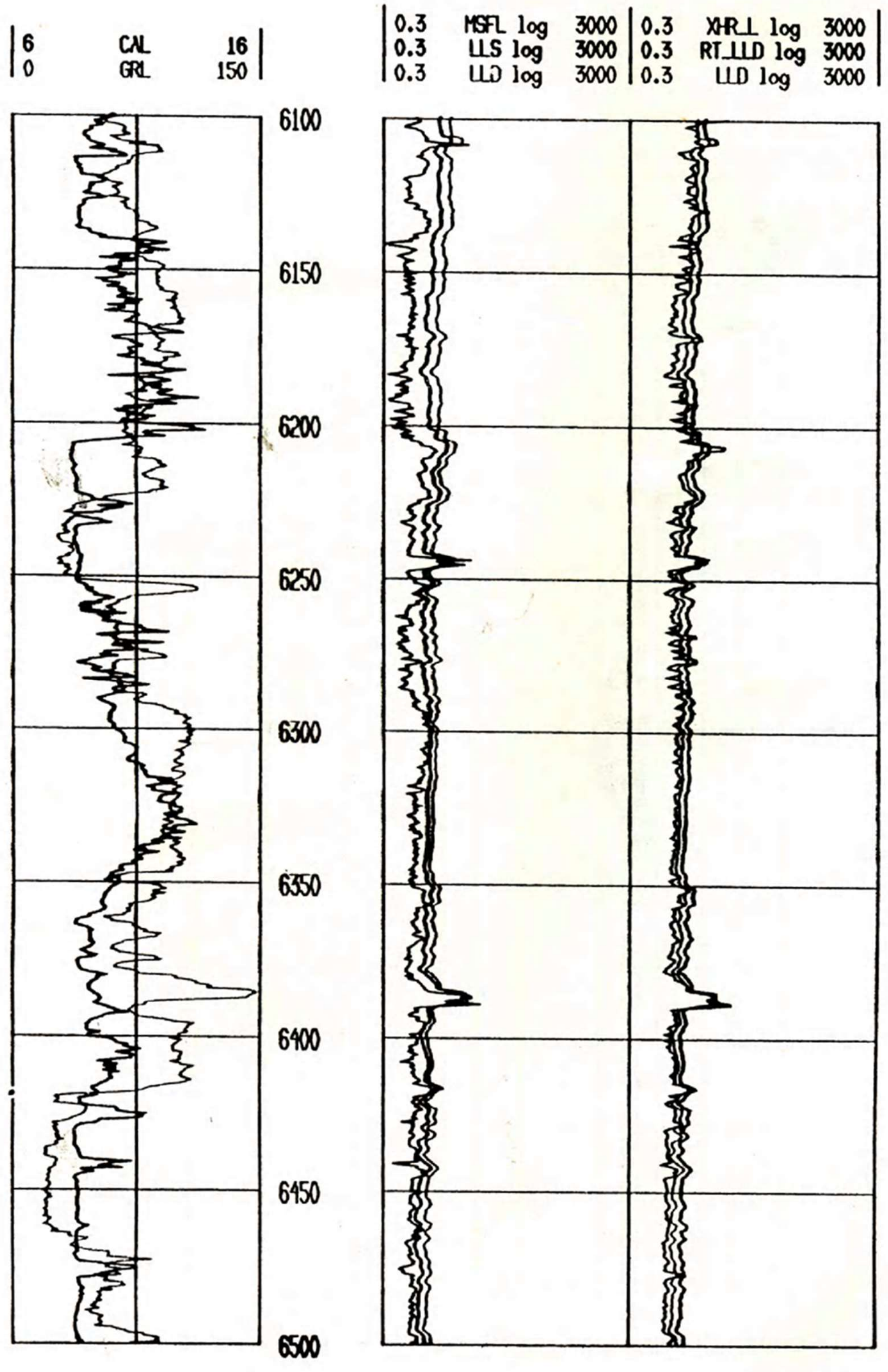
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0.3 LLD log 3000
0.3 XHR_L log 3000
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6350
6400
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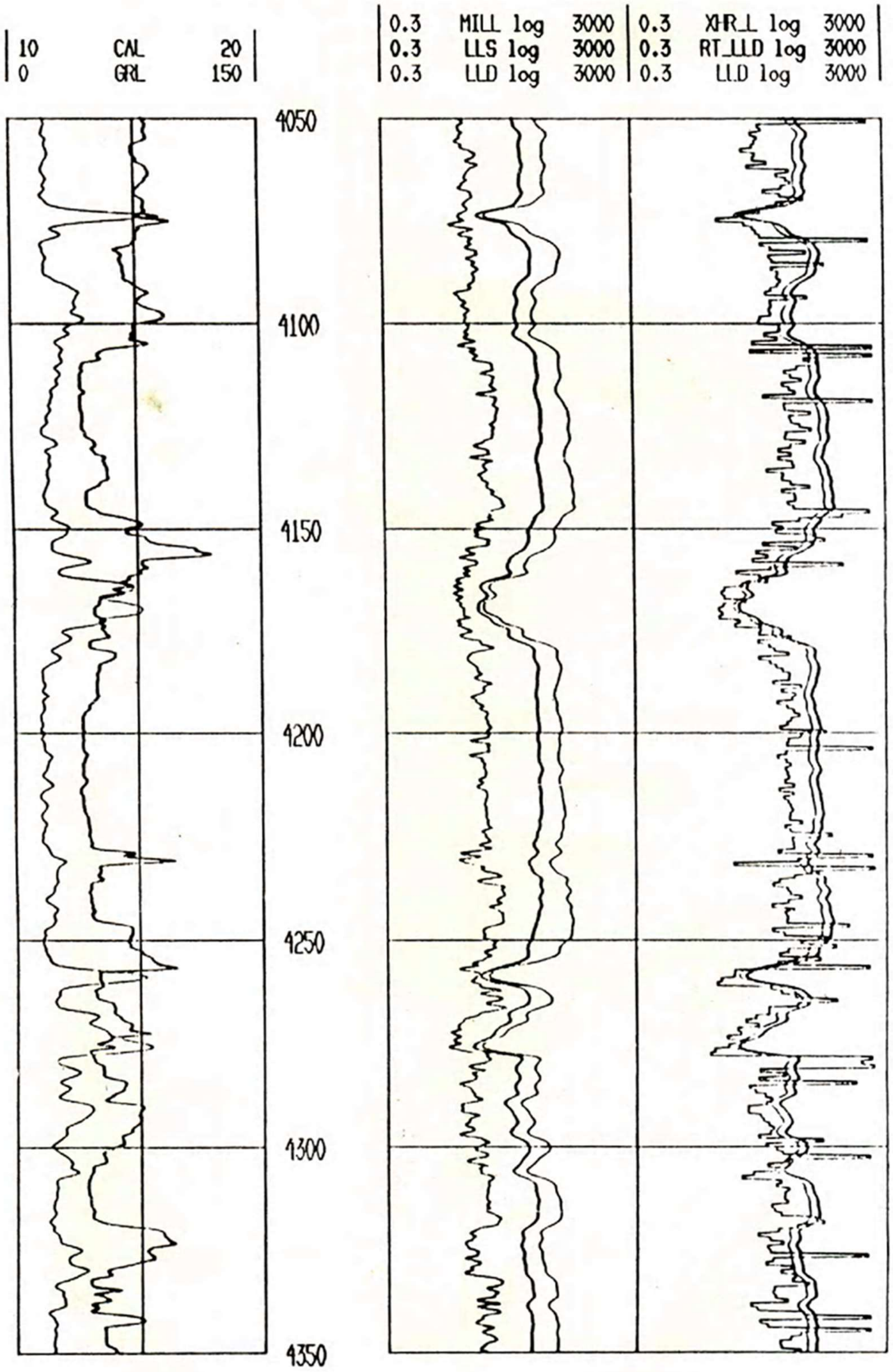
6500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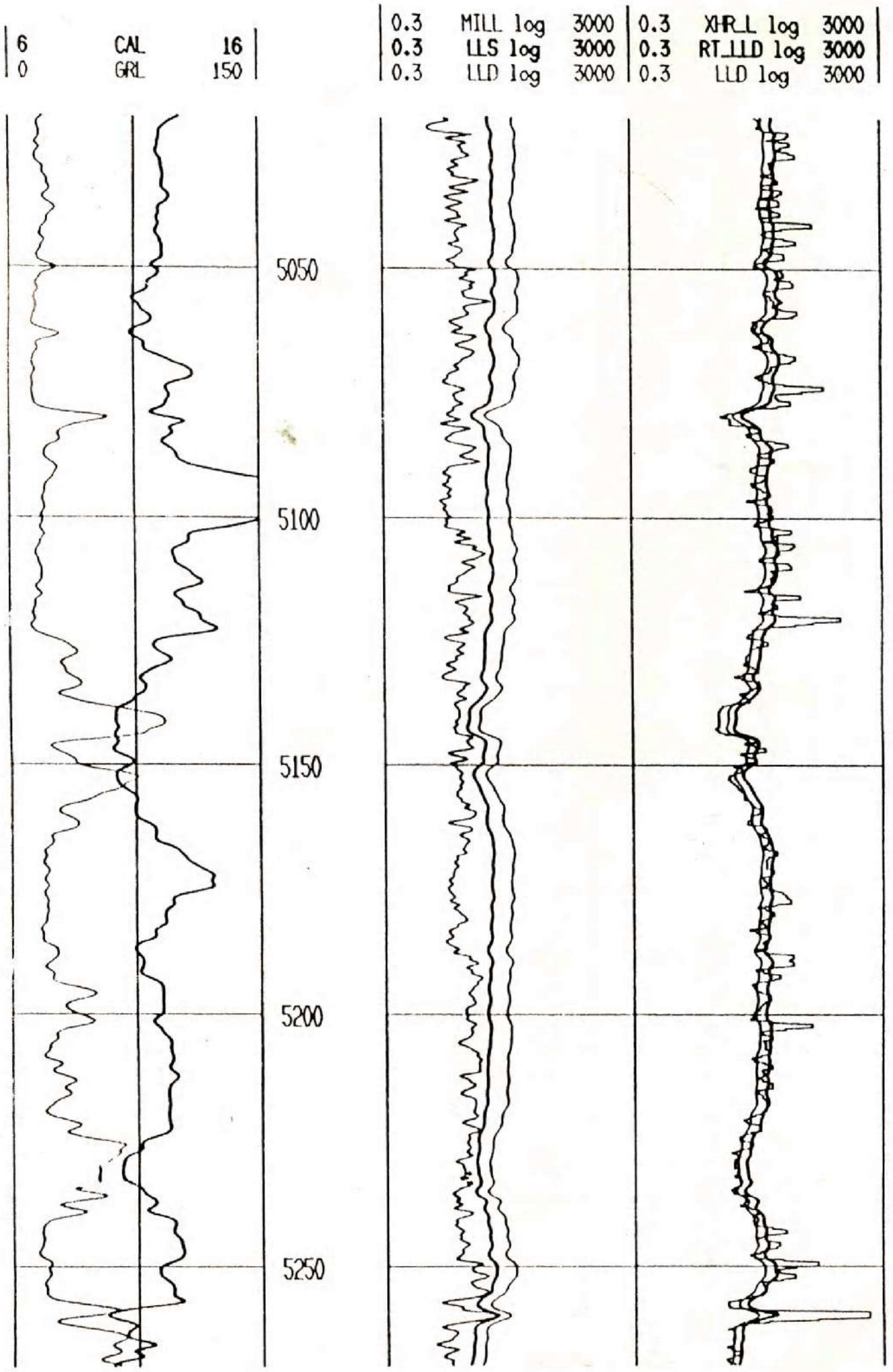
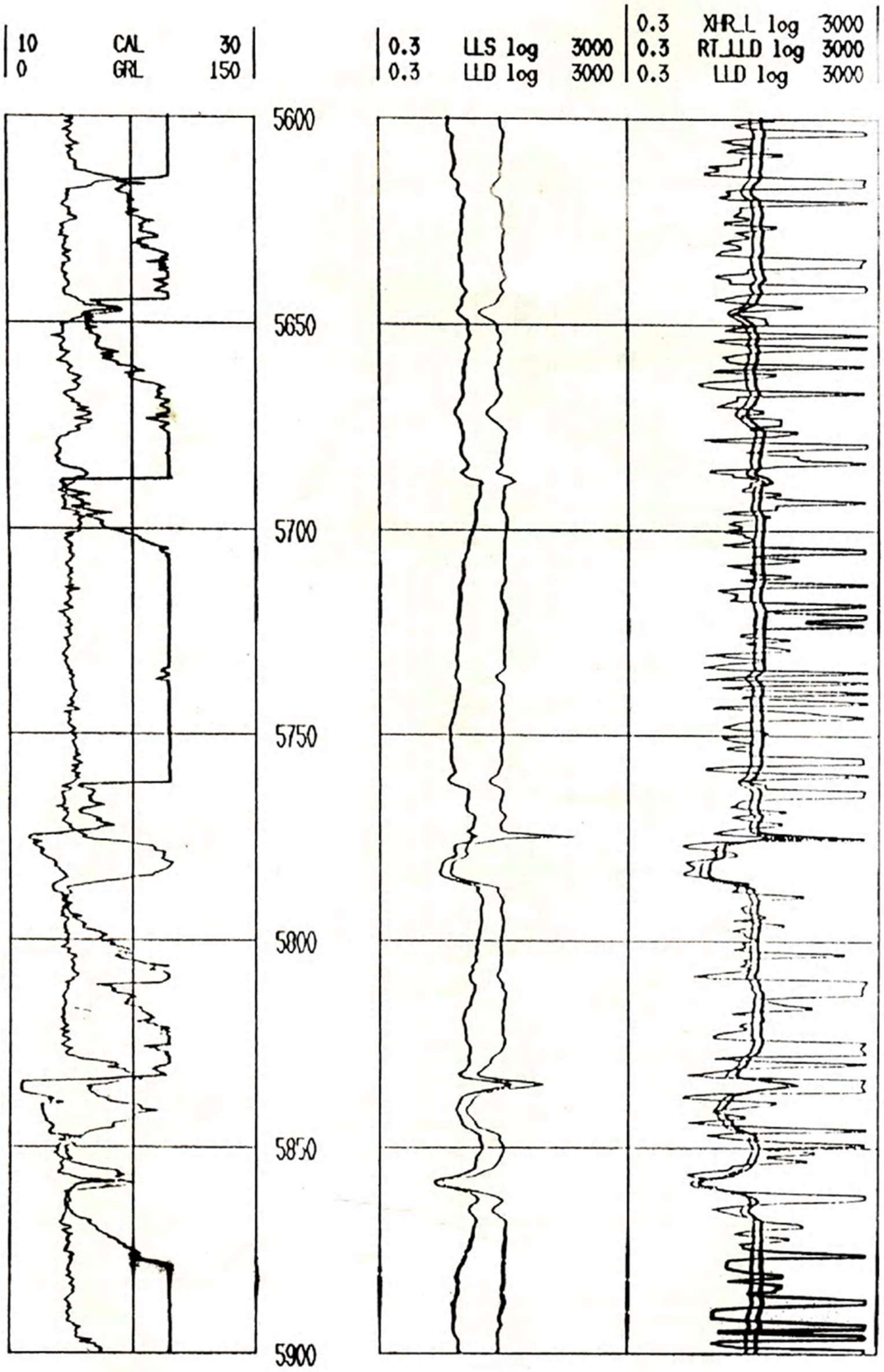
4300
4350

Figure 11: Fresh Water Environment Well—1.

Figure 9: Fresh Water Environment Well—2

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0.3 LLD log 3000
5600
5650
5700
5750
5800
5850
5900

Figure 11: Fresh Water Environment Well—3

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