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COMPARISONS OF CONVENTIONAL WIRELINE RESISTIVITY VERSUS LOGGING-WHILE-DRILLING/MEASUREMENT-WHILE-DRILLING LOGS IN THE OFFSHORE NORTHWEST JAVA SEA OF INDONESIA

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ABSTRACT

Many oil and gas companies are currently evaluating Logging-While-Drilling (LWD) or Measurement-While-Drilling (MWD) results as a possible alternative to conventional wireline logging measurements. Based on preliminary comparisons in the Offshore Northwest Java Sea (ONWJ) area of Indonesia, some differences occur between the conventional resistivities and those obtained from LWD/MWD in the same wells. Most of these differences can be interpreted and many reveal valuable information about the formation.

Some of the differences observed between the LWD/MWD and conventional resistivities can be used to locate permeable hydrocarbon zones which have become flushed with mud filtrate and therefore exhibit a difference in resistivity over time. Other differences can often be explained by differences in instrument response and design. Both laterolog and induction type conventional logs are used in the comparisons to LWD/MWD.

In several cases, the LWD/MWD measurements indicate higher resistivity, which leads to more hydrocarbon pay, when compared to the conventional resistivities, apparently due to less mud filtrate invasion at the time of the LWD / MWD measurement. In water bearing sands, however, the deep laterolog resistivities often read higher than either the LWD/MWD or deep induction measurements.

There are certain advantages as well as limitations to each type of resistivity device. Comparison of these different resistivity measurements in the same wells can help determine which type of resistivity data is appropriate for future wells in an area. However borehole conditions, deviation angles, and economic considerations are also major factors in deciding which type of resistivity instrument to use.

INTRODUCTION

Many major and as well as independent oil and gas companies are now re-evaluating traditional formation evaluation, commonly utilizing LWD/MWD technology as a replacement for routine wireline logging services. For simplicity, the terms "LWD/MWD" will be shortened to only "LWD" in this paper since resistivity is the primary item of focus LWD measurements are usually made within half an hour after the drill bit cuts the rock formation. The results are comparable with open hole wireline logs, and in some instances superior to wireline logs when invasion effects are great or when bore hole deterioration has affected the quality of wireline logs.

LWD measurements provide data that appear similar to wireline data. However, due to distinct tool designs, special operating procedures and different data acquisition systems, the logs acquired while drilling are different from wireline logs.

The data presented herein come from two types of LWD instruments. The conventional LWD resistivity instrument utilizes two transmitters and two receivers (2T/2R) to measure two resistivities, a phase (or shallow) resistivity and an amplitude (or deep) resistivity. A second type of LWD resistivity instrument utilizes four transmitters and two receivers (4T/2R) to obtain four different depths of investigation a phase resistivity, plus four different depths of investigation amplitude resistivity (Figure 1).

GEOLOGICAL SETTING

LWD examples discussed in this paper were obtained from 4 wells in the Offshore Northwest Java (ONWJ) area (Figure. 2). The logs are all from the Talang Akar Formation or the Main/Massive intervals of the Upper Cibulakan Formation within the Ardjuna Basin. The Ardjuna Basin is one of a series of sedimentary basins within the ONWJ area whose origins are associated with Eocene/early Oligocene rifting of the southern margin of the Sunda Platform. This rifting formed in response to the collision of the Sunda tectonic plate with the Indian-Australian Plate (Sujanto and Sumantri, 1977). The basin is subdivided into a series of half-grabens, with major north-south trending, down-to-the-west listric faults forming the eastern margins, and updipping flanks occurring on the west.

The Talang Akar formation comprises a Lower to Upper Oligocene syn-rift to rift-fill succession of largely non-marine deposits overlain by an Upper Oligocene to Lower Miocene post-rift succession of paralic to open marine sediments. The sediments were deposited within an extensive, flat lying coastal plain, over which northerly-derived post-rift deltaic coals, delta-front siltstones and sands were laid down. Later subsidence, possibly coupled with a eustatic rise in sea level, resulted in progressively more marine conditions, culminating in a thick succession of marine shales and carbonates of the Batu Raja Formation (Suria et al., 1994).

The Main/Massive Intervals of the Upper Cibulakan Formation was deposited during the Middle Miocene, at the end of Batu Raja deposition. There is strong evidence to suggest that a change in depositional environments occurred due to the major faults undergoing tectonic reactivation and growth during sedimentation (Atkinson and Kaldi, 1990). The Main/Massive sediments comprise interbedded sandstones, siltstones and shales with subordinate limestones (Purantoro et al., 1994). Regional evidence suggests that these sediments are shelfal to deltaic in origin and were deposited when a series of delta lobes prograded southward into the Ardjuna area (Atkinson et al., 1993).

LOG EXAMPLES

Main-Massive

Example 1: **LES-1 well (4700'-5700')**, 4T/2R LWD-Low Resistivity Pay vs. Higher Resistivity Pay in the Main/Massive Formation. An illustration of the response obtained from the LWD resistivity device that utilizes four different depths of investigation can be seen in Figure 3A, along with the corresponding wireline porosity and gamma ray measurements. Separation can be seen on the raw LWD curves when comparing the four different depths of investigation measurements. The measurements include extra shallow, shallow, medium and deep LWD resistivities each computed using the phase measurements. The extra shallow curve appears to be reading low in the shales, probably due to washouts beyond the large bit size of 12.25 inches. Four different depths of investigation amplitude resistivities are also available but are not presented here.

Figure 3B shows a comparison of the corrected LWD deep phase resistivity versus the dual laterolog deep resistivity for this same interval. The higher resistivity interval, Zone A, shows separation between the LWD resistivity and the deep laterolog resistivity. This separation is apparently due to invasion that occurred between the time that the LWD was recorded and when the wireline dual laterolog was run. Zone B also shows some separation although less then zone A.

Figure 4A is a crossplot/histogram that compares the dual laterolog deep resistivity (LLD) to the corrected resistivity from the deep LWD measurement (RT_LWD) and indicates average values of 1.3702 and 1.4531 ohm-m, respectively over a 1000 foot interval.

By using a crossplot of Rwa (apparent water resistivity) vs. GR (Gamma Ray) it is possible to separate hydrocarbon, water and shale zones and generate histograms for each (Dennis, 1984). The crossplot/histogram in Figure 4B gives an average shale resistivity of 1.2193 vs. 1.2255 ohm-m for the LLD and RT_LWD, respectively. The hydrocarbon zones are selected in the crossplot/histogram in Figure 4C and yield an average LLD resistivity of 4.3928 ohm-m compared to 7.1424 ohm-m for the RT_LWD.

The primary differences appear to occur in the hydrocarbon zones where invasion may be a factor. Figure 5 compares the diameter of invasion calculated from the LWD measurement versus that of the dual laterolog. Track 1 shows the calculated diameter of invasion from the LWD. Track 2 illustrates the calculated diameter of invasion of the dual laterolog using standard "tornado" charts. Track 3 compares the raw LWD and LLD deep measurements, while Track 4 shows the invasion corrected values. After the LLD resistivities are corrected for invasion, they tend to match the LWD resistivities better in the reservoir zones. However, in the shales it appears that the standard "tornado" chart may over-correct the dual laterolog.

Computed log analyses comparing the results obtained using the DLL vs. LWD measurements are shown in Figures 6A and 6B respectively. The depth track contains the reservoir flag on the left side while two pay flags are located on the right side. The leftmost payflag is the conventional pay flag using a porosity cutoff of 10 percent, a water saturation cutoff of 65 percent and a clay volume cutoff of 50 percent. The rightmost payflag is an experimental low resistivity/low contrast (LRLC) payflag that utilizes Rwa vs. clay volume crossplots to identify hydrocarbon zones similar to the previous crossplot in Figure 4C. Using the LLD resistivity, Zone A is identified as pay using both methods, whereas Zone B is identified only by the low resistivity Rwa LRLC method. The LWD resistivity analysis also identifies Zone A as pay and since the water saturation is lower than that from the LLD, the LWD shows more pay in the low resistivity LRLC Zone B.

Based on the difference between the LLD and LWD resistivities plus the computed LRLC analysis over Zone B, there appeared to be movable hydrocarbon in this low resistivity interval. A productivity test was performed which yielded gas production at a rate of 1.1 MMCFGPD, 20.4 BCPD, and 13.7 BWPD on a 1/2 inch choke.

A productivity test was also performed over Zone A which yielded gas production at a rate of 15.357 MMCFGPD, 313 BCPD, and 40 BWPD on a 1 1/4 inch choke.

Talang Akar

Example 2: **LU-1 well (10710'-11030')**, 4T/2R LWD Recorded and Time Lapsed Mode vs. LLD wireline Measurements in a deviated well over the Talang Akar Formation. Figure 7A, using the four depths of investigation LWD resistivity instrument shows the LWD deep resistivity compared to the LLD deep laterolog. Track 1 contains the gamma ray and caliper curves while Track 2 contains the LLD and recorded LWD resistivities. Track 3 compares the extra shallow LWD versus the deep LWD in the recorded mode while Track 4 shows the conventional wireline density and neutron logs. Zone A shows significant invasion between the extra shallow and deep LWD resistivities, indicated probable movable hydrocarbon. Zone B, in comparison shows only a small amount of invasion, indicating less movable hydrocarbon.

A comparison of logging while drilling (LWD) versus logging after drilling (LAD or washdown mode) can be seen in Figure 7B for the same example. Track 1 is the same as shown previously while Track 2 and 3 show the extra shallow versus the deep resistivity from the LWD and LAD mode, respectively. Track 4 compares the deep LWD resistivity to the deep LAD resistivity indicating a significant resistivity decrease in the after drilling mode. The LWD deep resistivity read approximately 100 ohm-m in Zone A in the recorded mode compared to only 30 ohm-m recorded after drilling in the washdown mode. This reduction in resistivity is probably due to invasion of the mud filtrate which flushed more hydrocarbon further away from the borehole over time. The time that elapsed between the first logging while drilling (LWD) and the logging after drilling (LAD) was approximately 60 hours.

A crossplot/histogram of the wireline LLD and the LWD recorded mode deep resistivities can be seen in Figure 8A. The average LLD resistivity is 44.242 ohm-m while the average LWD deep resistivity is 19.292. As seen from the previous figure, the deep laterolog LLD curve tends to read higher than the deep LWD resistivity in the shales in this deviated well. Figure 8B is a crossplot/histogram selecting the shales that give an average LLD reading of 34.597 ohm-m versus 10.792 ohm-m for the LWD. This significant difference could possibly be due to vertical anisotropy in the shales. The hydrocarbon Zone A selected in the crossplot/histogram in Figure 8C shows resistivities that agree more closely, 107.41 ohm-m for LLD and 92.429 ohm-m for LWD.

Computer analyses using the LLD and LWD deep resistivities can be seen in Figures 9A and 9B, respectively. The presentations are the same as described previously. Both computer analyses indicate hydrocarbon in both Zones A and B. Zone A shows almost identical water saturation between the LLD and LWD results. Zone B shows slightly higher water saturation using the LWD resistivity. A productivity test over Zone B indicated no flow while a separate test over Zone A yielded 8.552 MMCFGPD, 1411.8 BOPD, and 0 BWPD.

Example 3: **TZ-1 well (6600'-6900')**, 2T/2R LWD vs. LLD in Water Sand - Conventional Two Depths of Investigation Instrument. Figure 10 shows a conventional LWD deep amplitude resistivity (RT_LWD) versus a dual laterolog deep resistivity (LLD) and versus a special high resolution magnetic pulse deep reading induction resistivity device (RT_MPI). A crossplot/histogram (Figure 11A) of this interval shows the average values to be 6.4003 ohm-m for the LLD, 4.7391 ohm-m for the RT_MPI and 3.5571 ohm-m for the RT_LWD curves.

Figure 11B is a crossplot/histogram with the shales selected. Average resistivity values are 7.9121, 5.4796, and 4.3222 ohm-m for the LLD, RT_MPI, and RT_LWD, respectively.

In the water sand at Zone A the LLD reads much higher than the LWD resistivity. However, the LWD resistivity agrees very well with the special high resolution deep reading magnetic pulse induction resistivity measurement in the water sand except for the expected differences in bed resolution. Figure 11C illustrates a crossplot/histogram over the selected water sand and shows average values of 1.5326, 1.2764 and 0.97038 ohm-m for the LLD, RT_MPI, and RT_LWD, respectively.

Example 4: **SBA-2 well (7900'-8400')**, 2T/2R LWD vs. Dual Laterolog in Hydrocarbon and Water Zones - Conventional Two Depths of Investigation Instrument. Figure 12 shows a conventional 2T/2R LWD resistivity device compared to a dual laterolog. The dual laterolog indicates movable hydrocarbon in Zones A and C and probable mud filtrate invasion in the water Zone B. The resistivity from the deep laterolog (LLD) reads higher than both the phase and attenuation LWD resistivities in the water Zone B. Conventional "tornado" chart invasion corrections to the LLD would make the difference even more pronounced.

Figure 13A is a crossplot with histograms showing average values of 12.649, 7.9793, and 7.9850 ohm-m for the LLD, PSR_LWD, and ATR_LWD curves, respectively. Selecting the shales yields average values of 10.229, 5.5833, and 6.2063 ohm-m for the same respective curves

(Figure 13B). Hydrocarbon average readings are 16.673, 13.266, and 16.969 ohm-m (Figure 13C), while the average water readings are 1.5159, .98397, .9617 ohm-m (Figure 13D) for the same ordered curves.

An initial well test for Zone C yielded approximately 5.336 MMCFGPD, 1104 BOPD, and 20 BWPD on a 1/2 inch choke.

CONCLUSIONS

1. Logging While Drilling (LWD) resistivity instruments provide an alternative method to conventional resistivity devices for evaluating oil and gas wells.

2. In several cases the LWD resistivity appears to be less affected by invasion if recorded immediately while drilling.

3. LWD resistivity recorded after drilling or in the "washdown" mode may be reduced due to saline mud invasion and could lead to pessimistic log evaluation. For accurate results the LWD resistivity should be recorded while drilling with the tool as close to the bit as possible to reduce invasion effects.

4. The dual laterolog deep resistivity LLD often reads higher in the water sands than either the LWD or induction resistivity instruments. Since the LWD resistivity instruments used in this comparison are electromagnetic devices, their responses are more similar to induction type measurements. Some theoretical modelling has been done to explain why the dual laterolog may read higher than induction logs in water sands (Theys, 1995).

5. More work is needed to fully understand all of the differences between LWD resistivity instruments and conventional resistivity devices.

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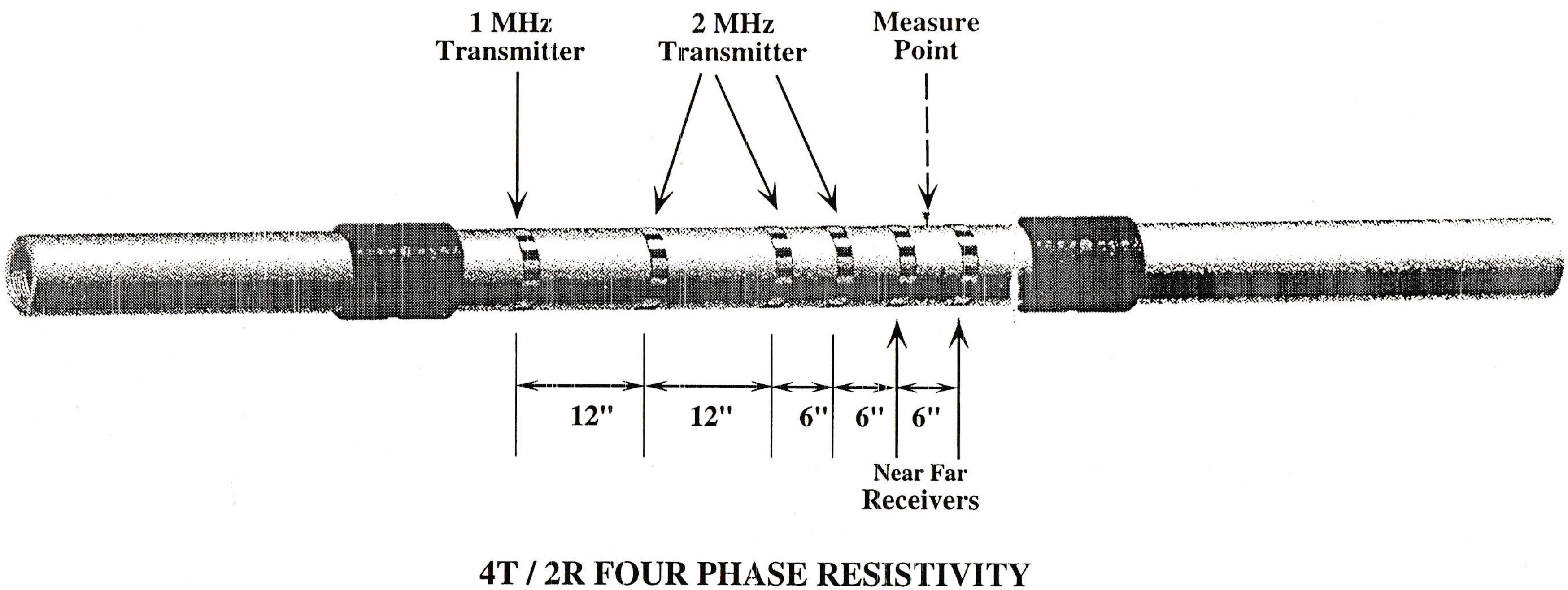


Figure 1. 4T / 2R Four Phase Resistivity

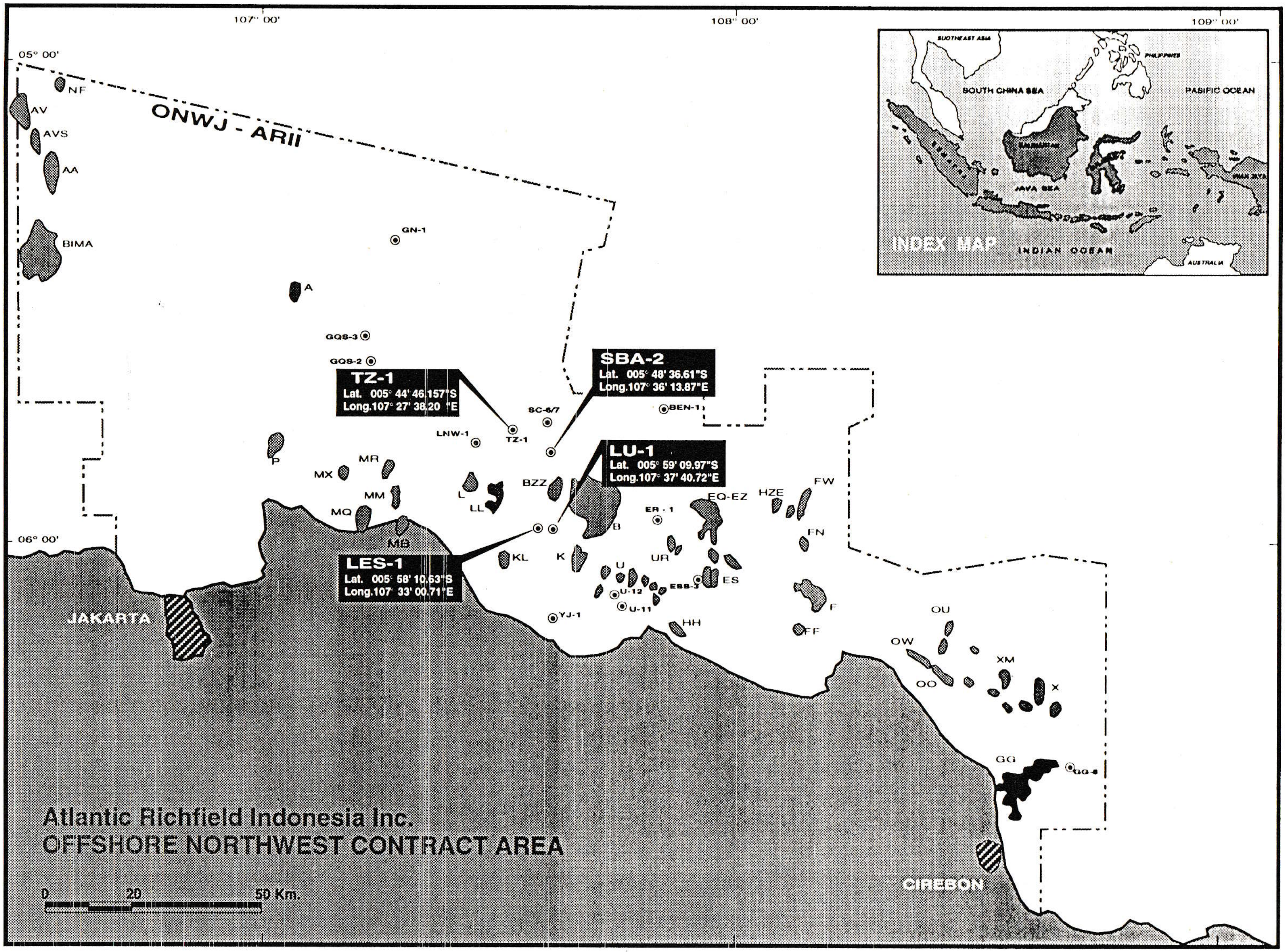
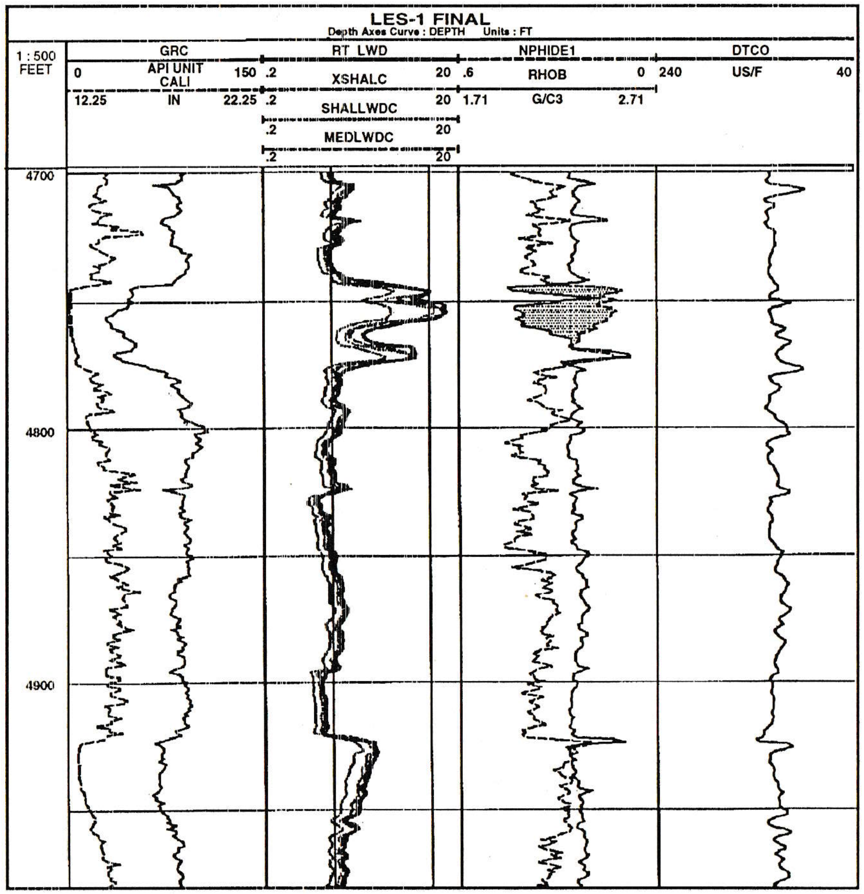


Figure 2. LWD Study Geological Area



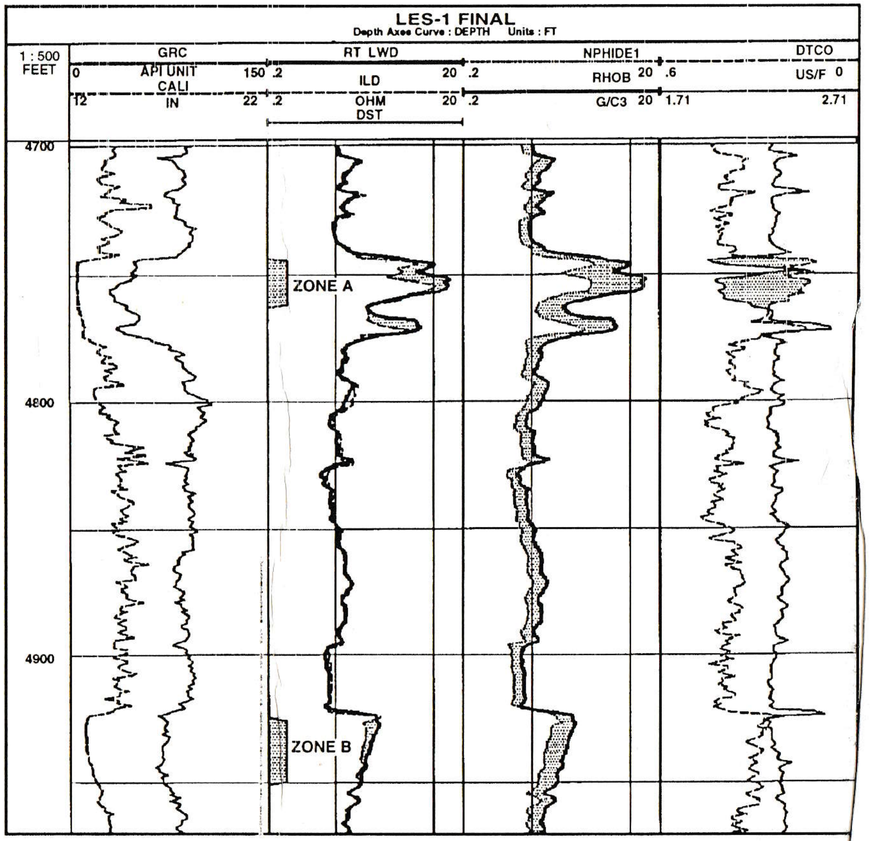
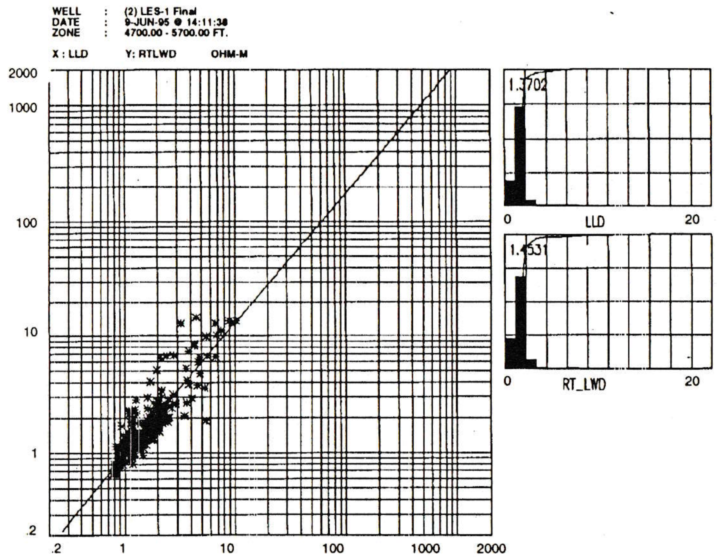
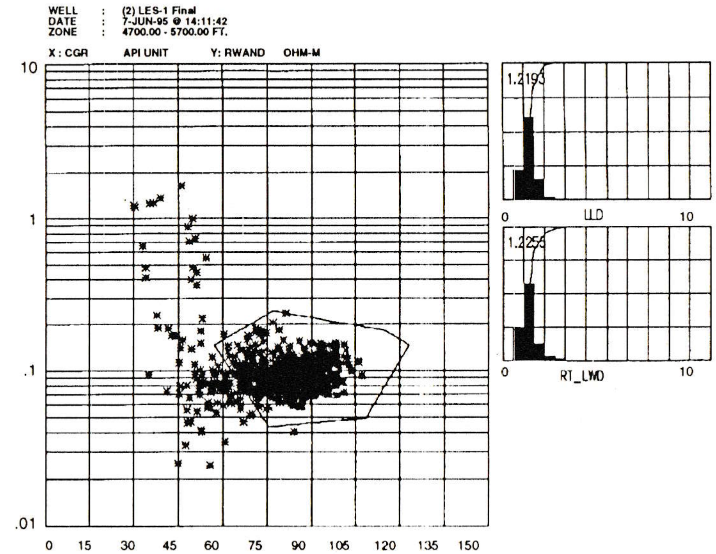


Figure 3A. Example 1 : LWD 4T / 2R Resistivity Log with Wireline Porosity Logs

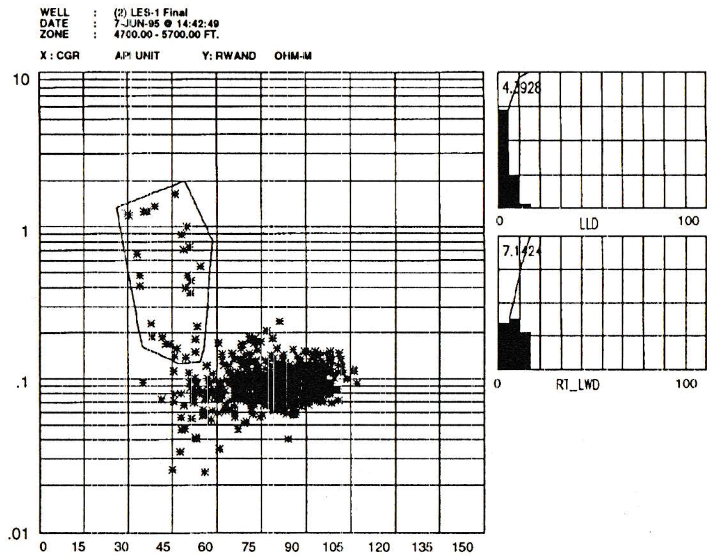
Figure 3B. Example 1 : Corrected LWD 4T / 2R Deep Resistivity Log vs. Dual Laterolog Resistivity



(A)



(B)



(C)

Figure 4. Crossplots Showing Histogram Averages of LWD 4T / 2R Resistivity Log vs. Dual Laterolog Comparison for (A) Total Interval (B) Shales and (C) Hydrocarbons for Example 1

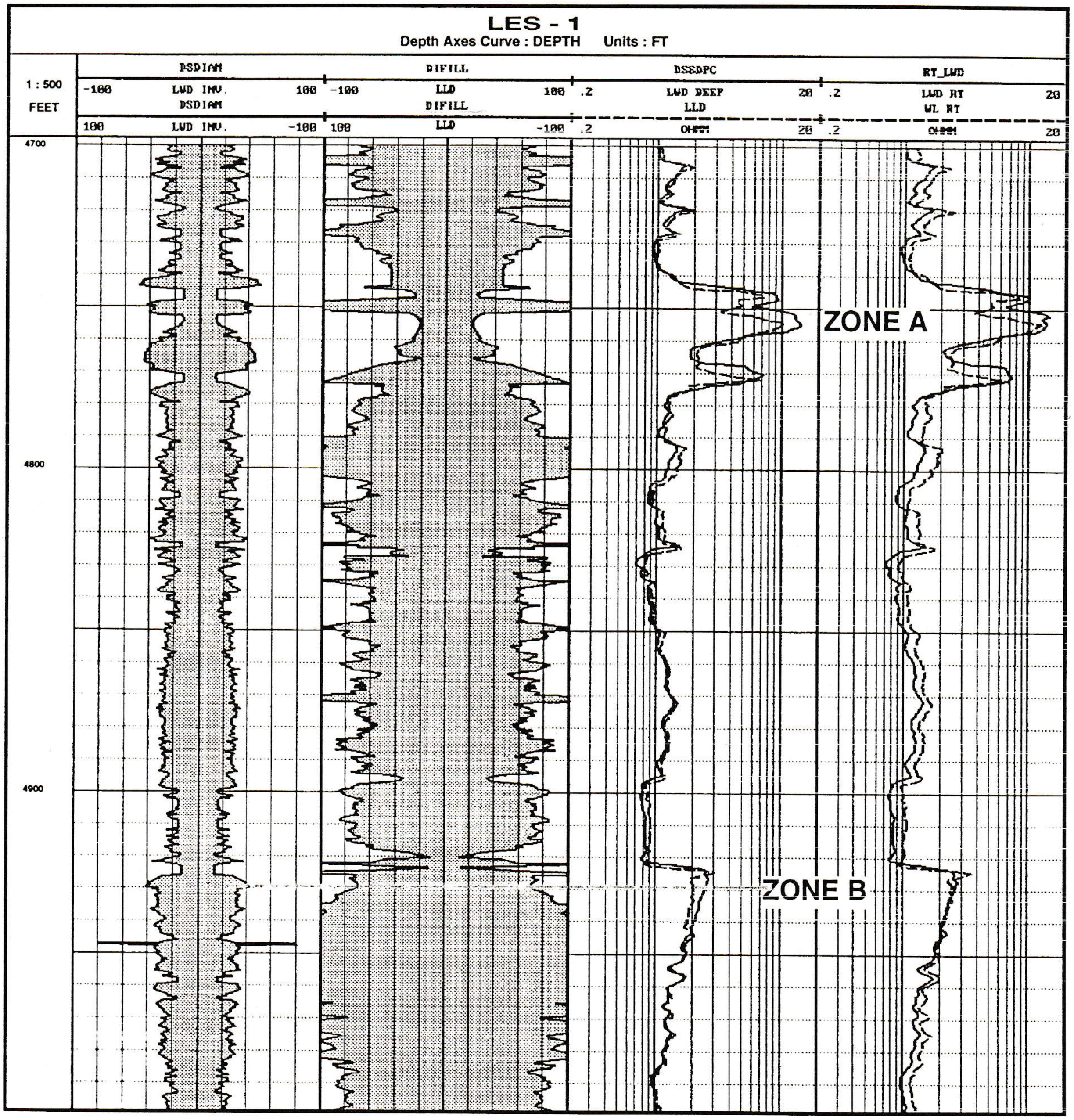


Figure 5. Diameter Of Invasion Calculations for the LWD 4T / 2R Resistivity Log and the Dual Laterolog for Example 1

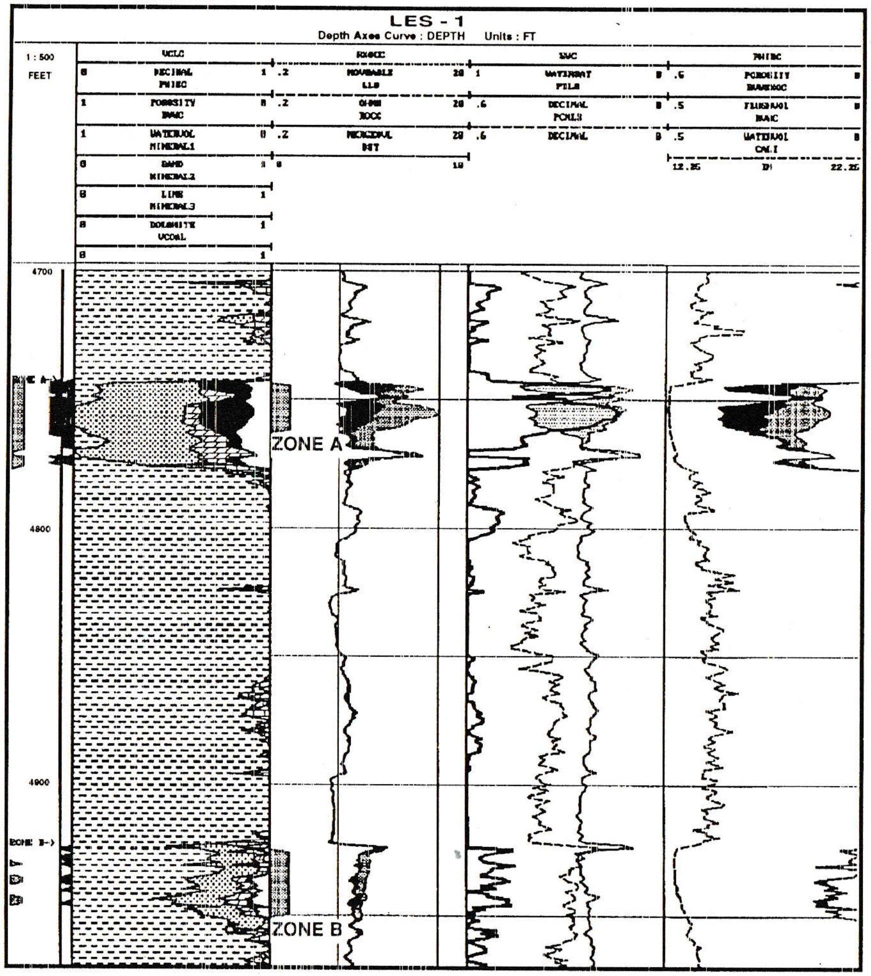


Figure 6A. Computer Log Analysis Using the Dual Laterolog for Example 1

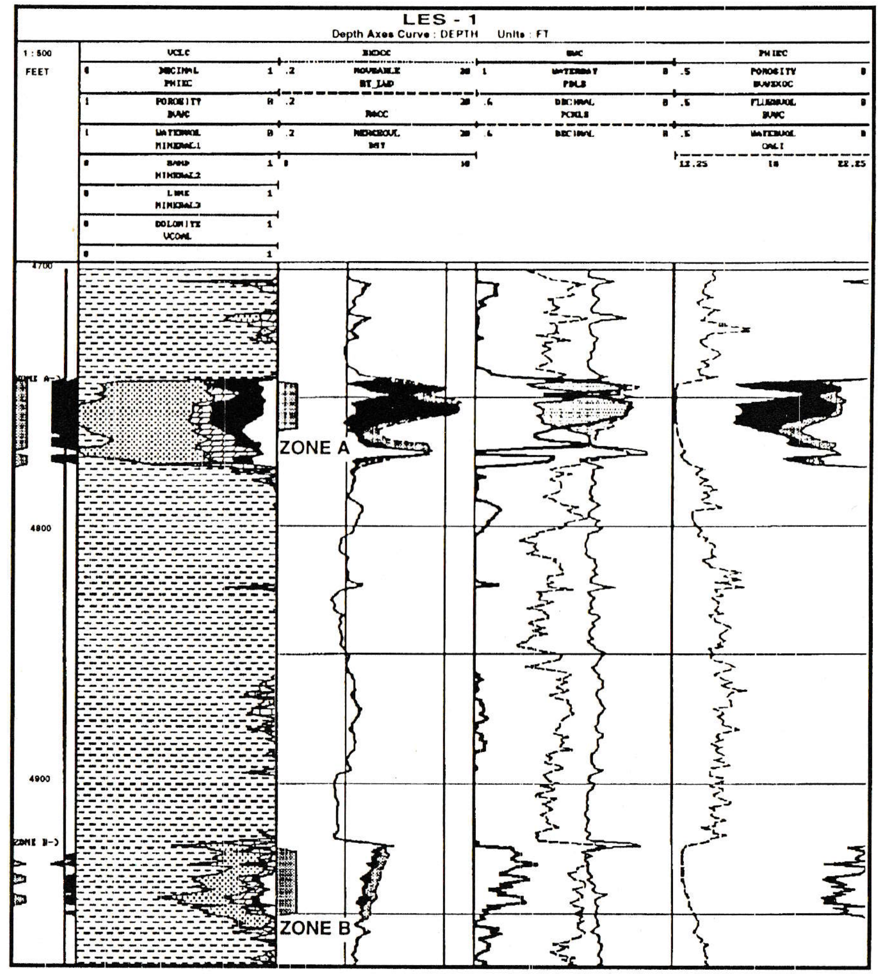


Figure 6B. Computer Log Analysis Using the LWD 4T / 2R Resistivity Log for Example 1

LEGEND :

	BADHOLE		SHALE		DOLOMITE / HEAVY MINERALS
	SAND		LIMESTONE		COAL

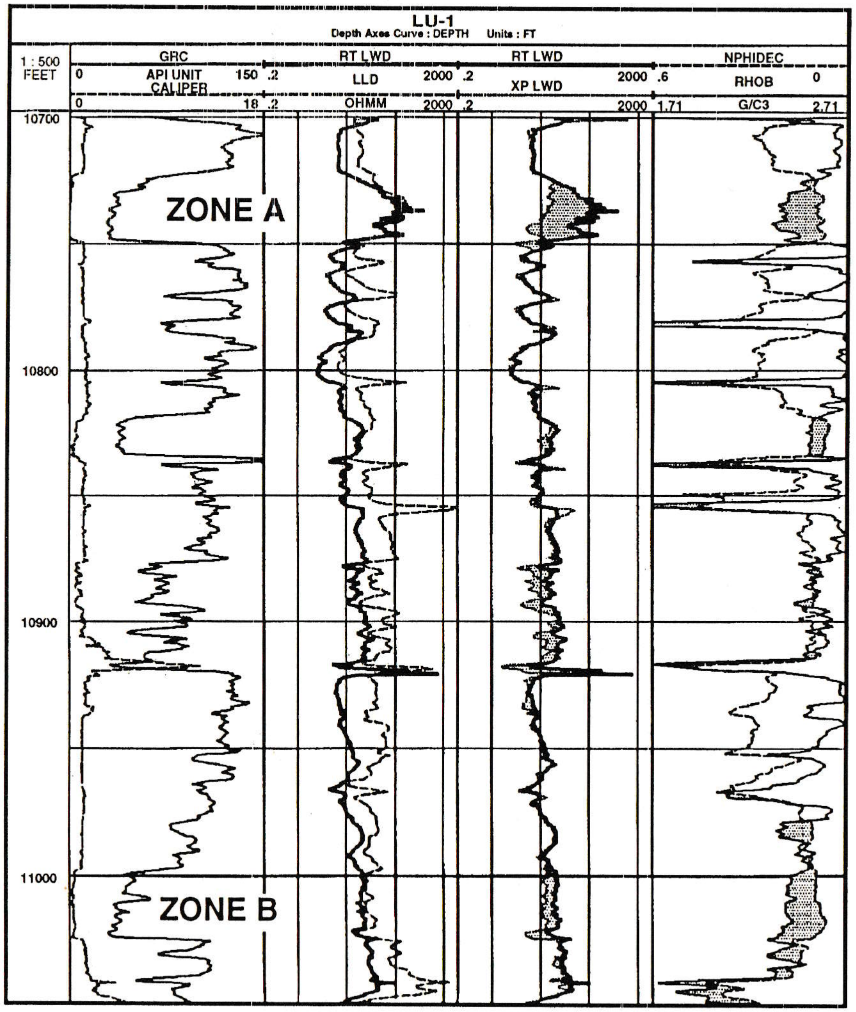


Figure 7A. LWD 4T / 2R Recorded Mode Resistivity Log vs. Deep Laterolog for Example 2

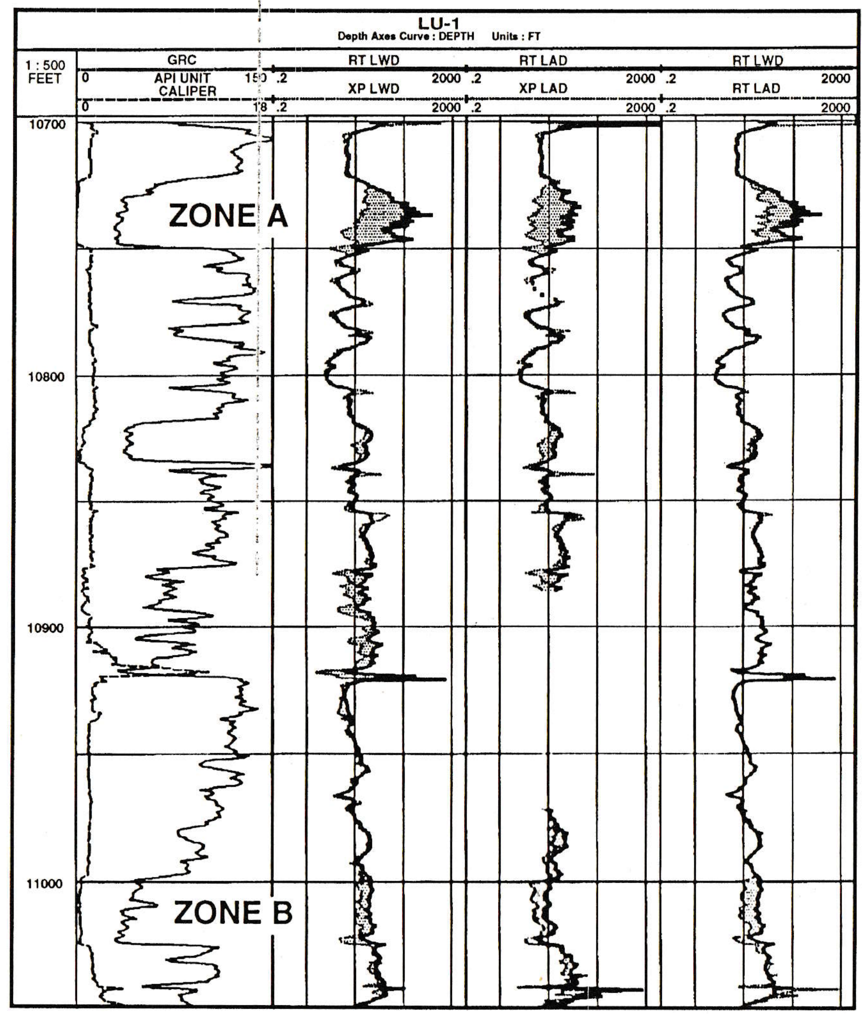


Figure 7B. LWD 4T / 2R Recorded Mode Resistivity Log vs. LAD 4T / 2R Time Lapse Mode Resistivity for Example 2

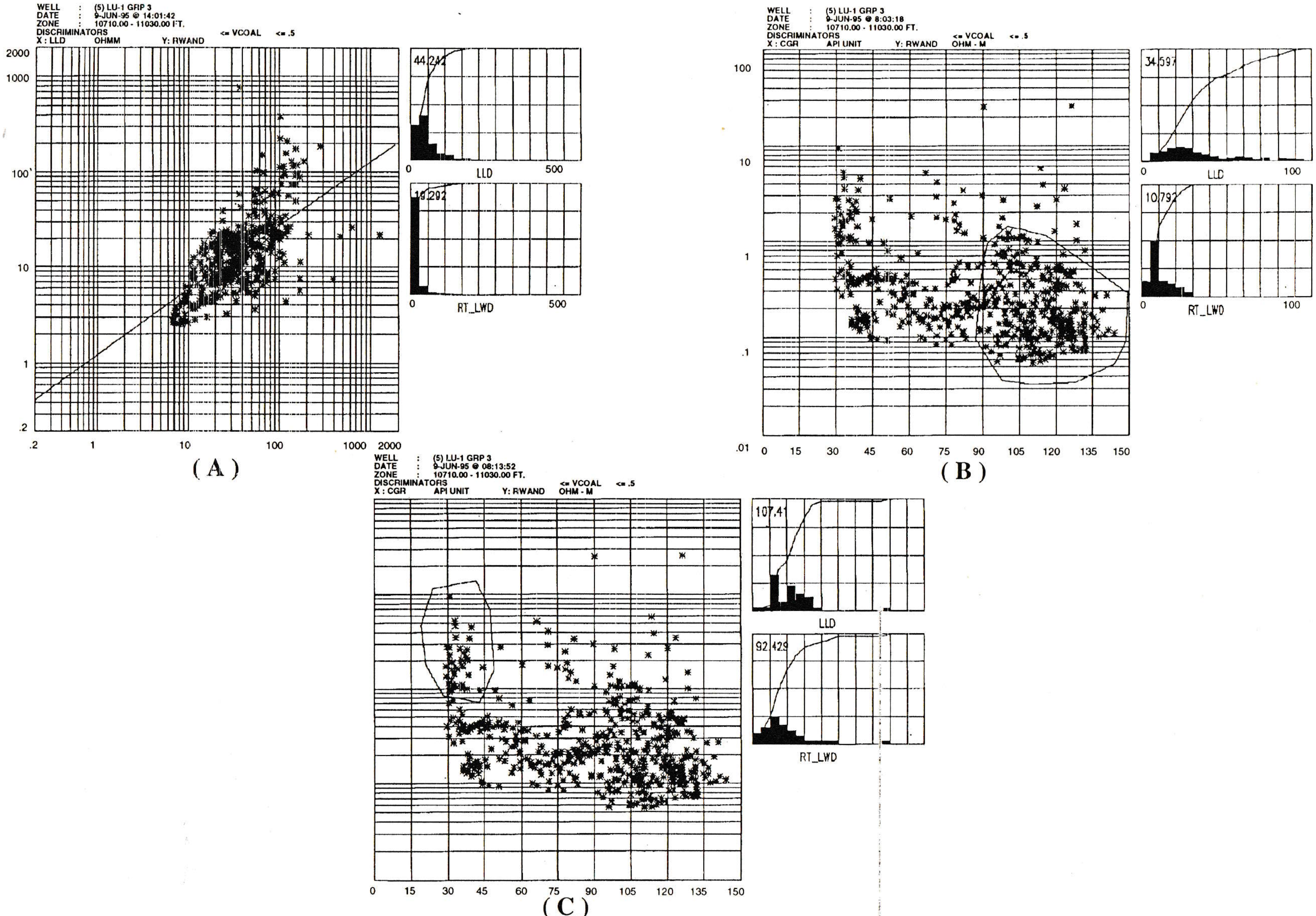


Figure 8. Crossplots Showing Histogram Averages of LWD 4T / 2R Resistivity Log vs. Dual Laterolog Comparison for (A) Total Interval, (B) Shales and (C) Hydrocarbons for Example 2

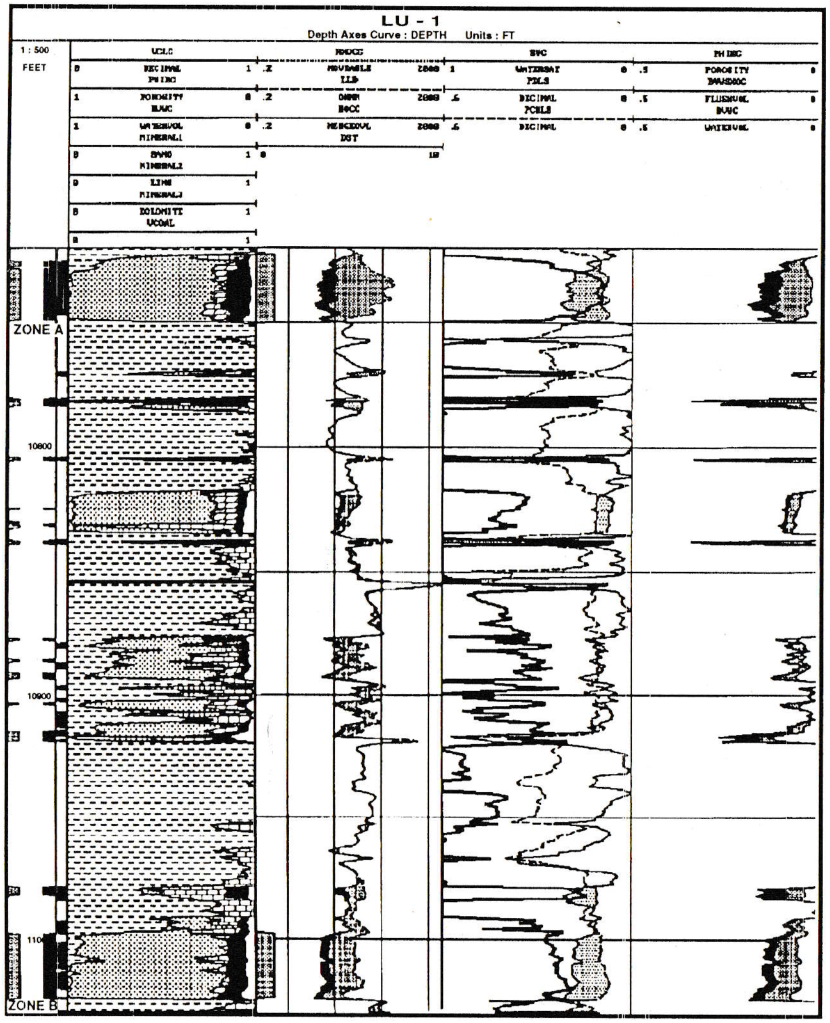


Figure 9A. Computer Log Analysis Using the Dual Laterolog for Example 2

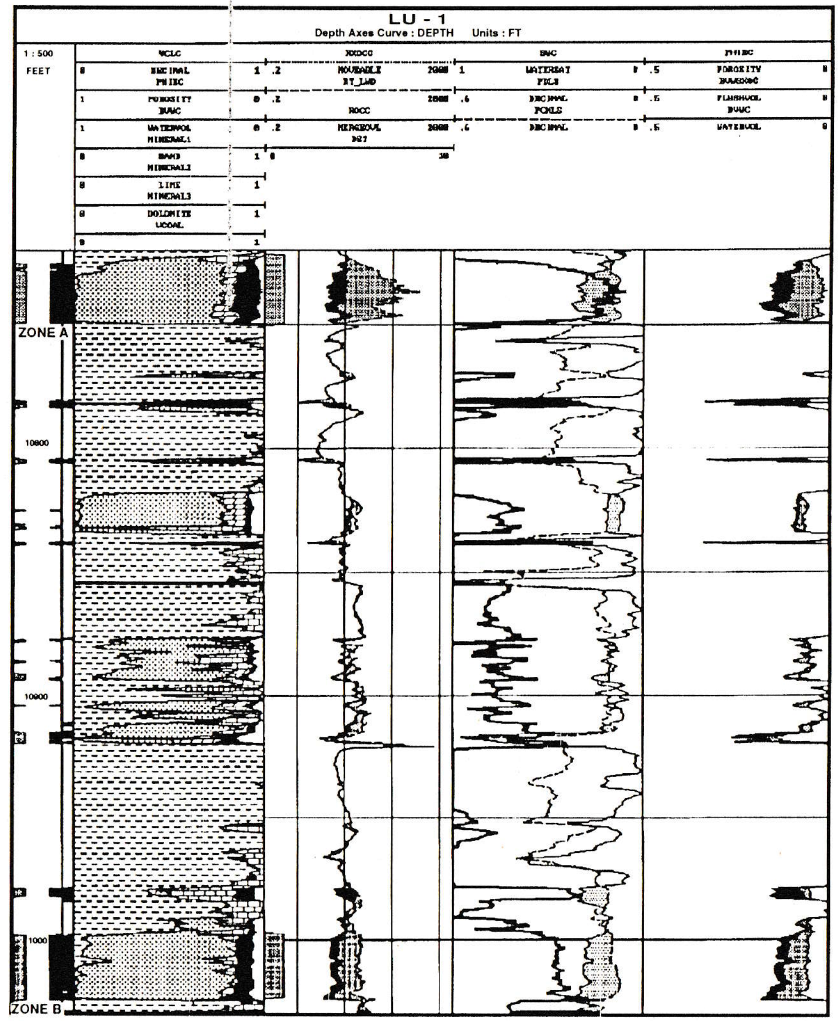
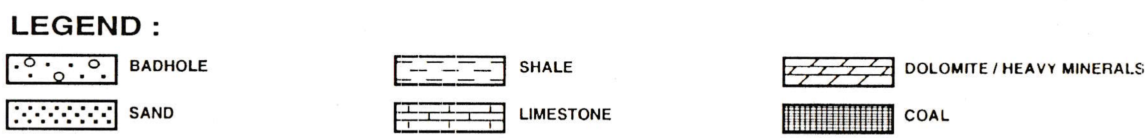


Figure 9B. Computer Log Analysis Using the LWD 4T / 2R Resistivity Log for Example 2



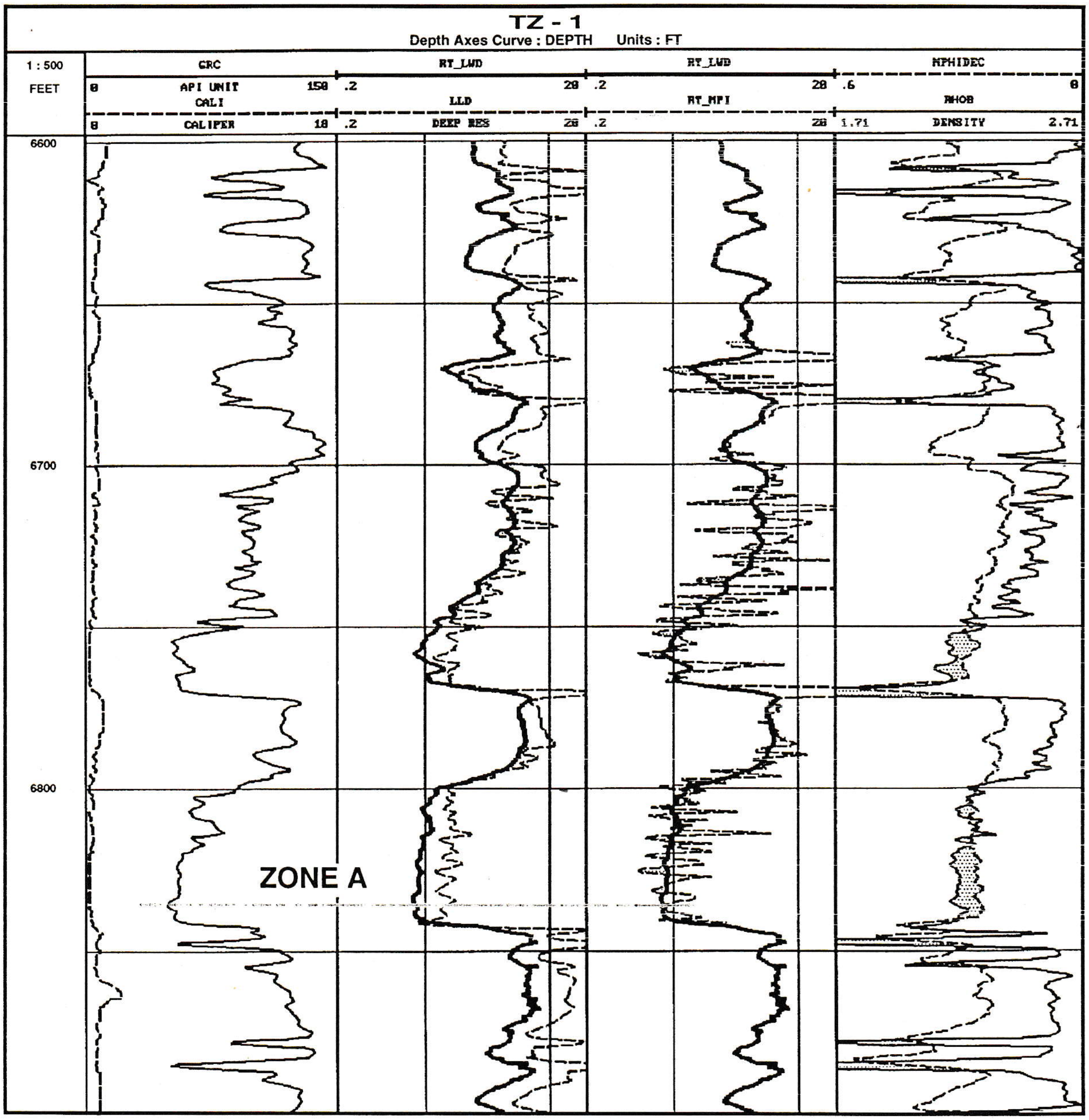


Figure 10. LWD 2T / 2R Resistivity Log vs. Dual Laterolog and vs. High Resolution Magnetic Pulse Deep Induction Resistivity for Example 3

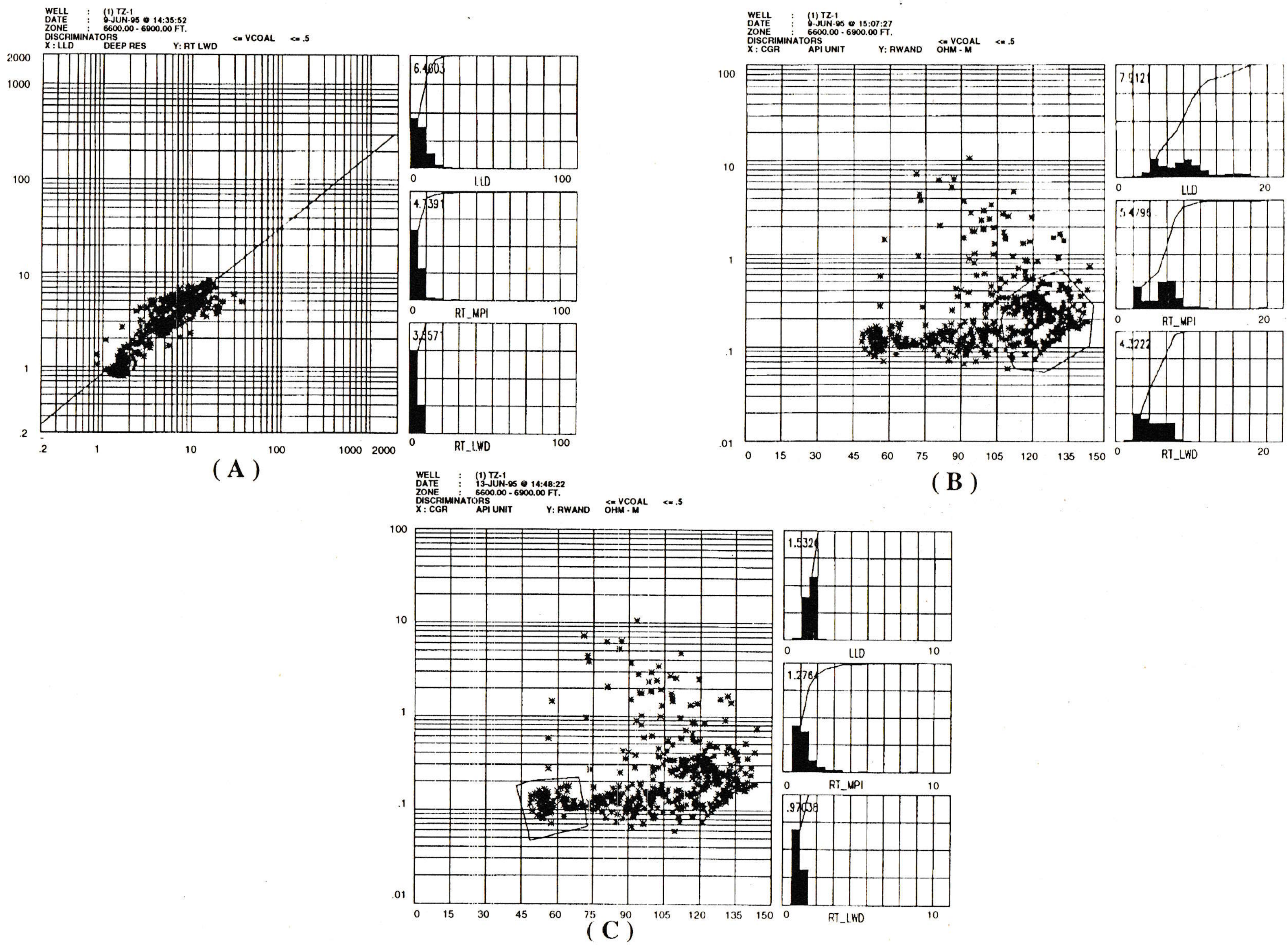


Figure 11. Crossplots Showing Histogram Averages of LWD 2T / 2R Resistivity Log vs. Dual Laterolog and vs. Magnetic Pulse Induction for (A) Total Interval, (B) Shales and (C) Water Zone for Example 3

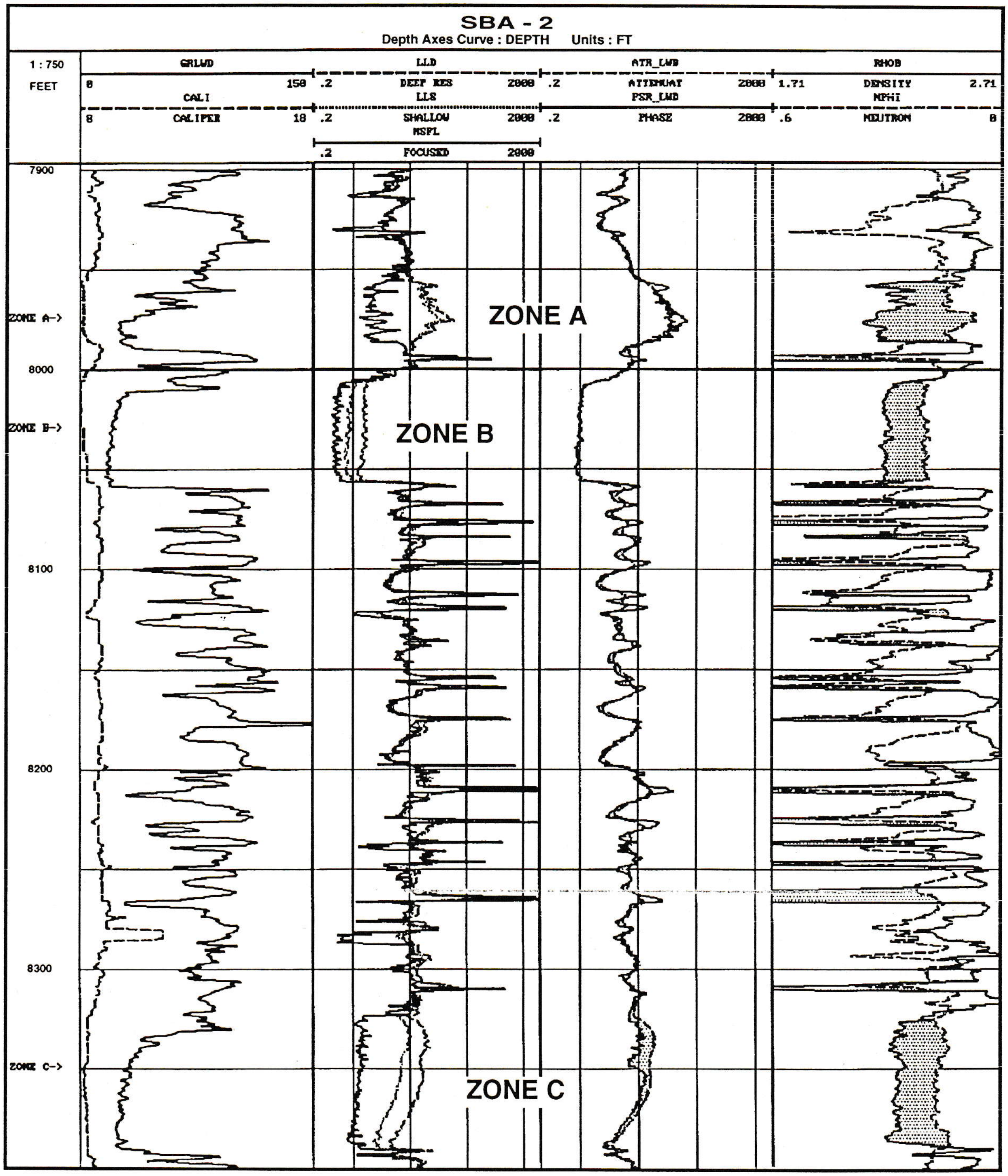


Figure 12. LWD 2T / 2R Resistivity Log vs. Dual Laterolog Resistivity for Example 4

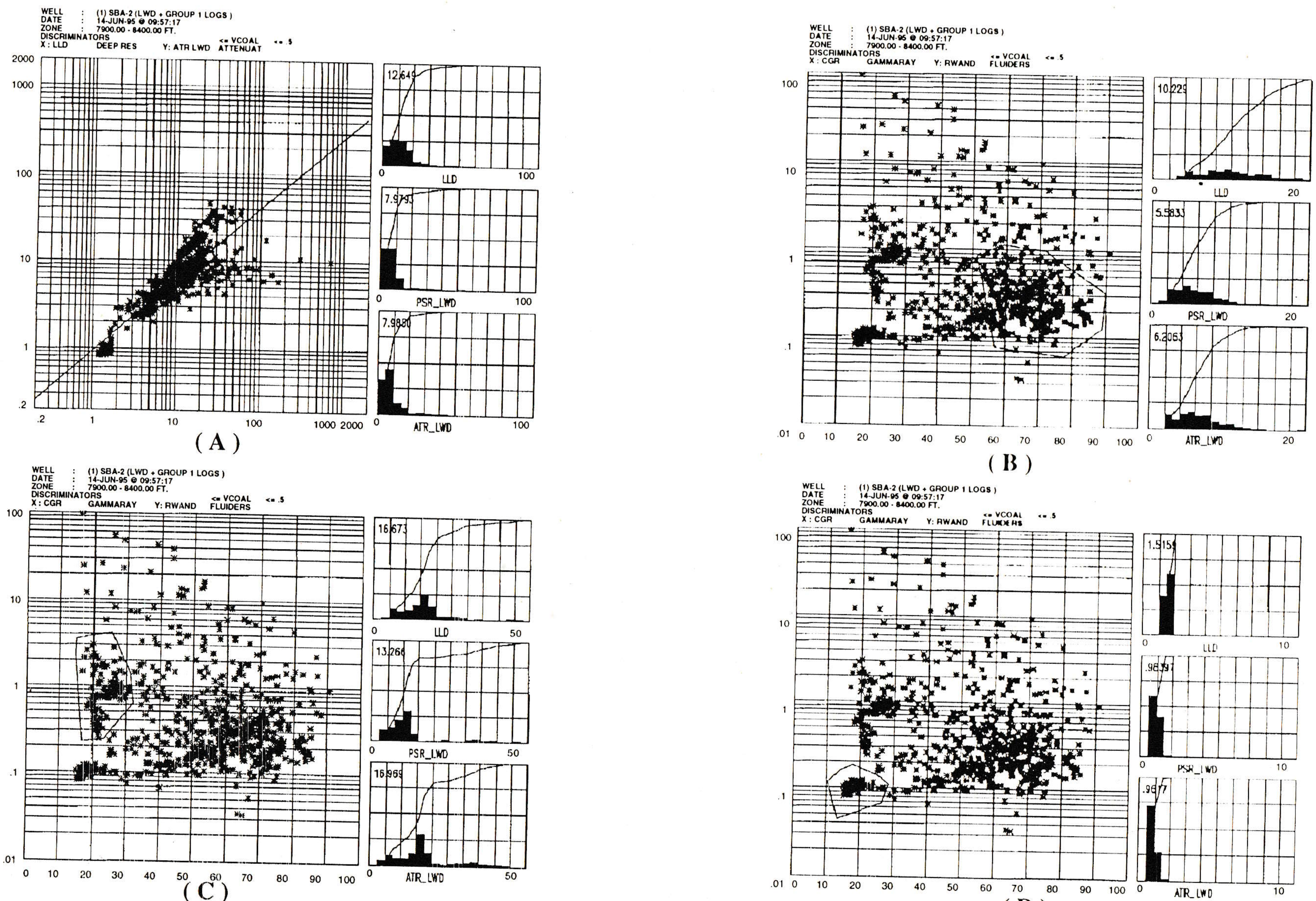


Figure 13. Crossplots Showing Histogram Averages of LWD 2T / 2R Resistivity Log vs. Dual Laterolog for (A) Total Interval, (B) Shales, (C) Hydrocarbon and (D) Water for Example 4