RESERVOIR MONITORING TOOL (RMT) - AN AID IN EXPLOITING HYDROCARBONS IN DEPLETED RESERVOIRS

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ABSTRACT

Determining the left over hydrocarbon saturation behind the casing and its exploitation in depleting reservoirs is always challenging. Periodic measurement of saturations behind casing helps in diagnosing the production problems such as water influx and water injection breakthrough. It helps in planning the work over jobs for better exploitation of hydrocarbons. It is still more complicated in the fields where water injection is going on for maintaining the reservoir pressures. Reservoir Monitoring Tool (RMT), i.e C-O logging, in the cased-hole environment is very robust in establishing locales for leftover Oil-Gas saturation in depleted fields.

The results have been confirmed in many fields, primarily through production test results. RMT application in the south Cambay basin is an extension to this confirmation. RMT derived results in south Cambay basin helped: identify depleted zone(s) and also lent assurance to undertake perforation in shallower sweet zone(s) for sustained hydrocarbon production and improve recovery. Thus the efficacy of the tool has qualitatively been proved at both ends of reservoir fluid saturation — one, when reservoir is fully saturated with water having SW ~ 100%, and two, against hydrocarbon bearing zones having SW ~ 50-60%.

RMT was logged in different fields in Ankleswar Asset (ONGC) and the results enabled to recomplete in other existing reservoirs on establishing depleted zones as well as gave opportunity to recover left over oil in the producing zones. Several case histories of RMT results (in both gas as well as oil wells) and remedial measures taken have been discussed in the paper.

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INTRODUCTION

In cased-hole applications, the carbon-oxygen measurement using pulse neutron spectrometry is an established technology to sense presence of carbon in hydrocarbons. In the event, the formations happened to display moderate to high porosity values, the measurement offers a viable option even to quantify saturation values.

Reservoir Monitoring Tool (RMT) is a pulsed neutron device that measures Carbon-Oxygen Ratio (C/O) in In-elastic mode and Capture Cross-Section in Sigma mode and is a dual detector, 2-1/8 inch (54 mm) diameter tool. The detectors are bismuth germinate scintillation counters, which leads to capture higher count rates, thereby increasing signal to noise ratio. The near space detector is 1 inch long, while the far spaced detector is 6 inches long. They are spaced 11.5 inches and 20.5 inches respectively from the source. High-energy neutrons are bombarded into the formations and the inelastic gamma and the capture gamma spectra are recorded. The spectral data is then utilized to extract C/O, Calcium-Silicon Ratio (Ca/Si), Bulk Sigma and Elemental Yields which are used for interpretation.

The preferred mode of data acquisition in formations having low salinity waters or of unknown salinities is C/O. The basic principle of C/O mode is that hydrocarbons have carbon and virtually no oxygen and water has oxygen but no carbon. Hence in a porous rock, as the hydrocarbon replaces water, carbon concentration increases and oxygen concentration decreases. Therefore the ratio of Carbon to Oxygen increases. However the increase in C/O (COIR) could also occur if the sands are replaced by lime. This is so because the composition of lime is $CaCO_3$. Thus the need of another curve which will tell us whether the increase in C/O is either due to hydrocarbon or is it due to lime. This curve is Ca/Si (LIRI). To summarize, if in a given clean reservoir the C/O increases without any increase in Ca/Si, then there is a very good probability that the reservoir is saturated with hydrocarbon.These ratios are then converted to Oil saturation values for a known porosity, through fan charts developed in laboratory measurements.

The basic principle of Capture (Sigma) logging is that, Neutrons, which are bombarded into the formation, become thermalised through repeated collision with the nuclei. The thermal neutrons are captured by the formation whose rate depends upon the type of concentration of element in the formation and the capture cross-section of the formation fluid. The decay rate of the capture gamma is therefore the direct function of formation and the pore fluid. Capture (Sigma) mode is more useful to distinguish between oil and water if the formation water salinity is very high or otherwise in the detection of gas bearing intervals from oil / water bearing intervals in a fresh water regime.

The capture spectrum is fitted with a composite spectrum derived out of pure element spectra, obtained in the laboratory, through computer modeling and using least square fitting procedure. This allows determinations of the relative contributions of basic elements like: H, Ca, Si, Fe, Cl, K, S, and Ti.

Both the modes have been used very effectively to detect and quantify left over oil and gas saturation values in different wells of cambay basin,especially in Gandhar, Ankleshwar and other adjoining fields of Ankleshwar Asset.

RMT APPLICATION IN GANDHAR FIELD:

Gandhar field is located about 37 km North West of Bharuch town and is part of Bharuch Jambusar block (Fig.1). The field is spread over an area of approximately 240 sq km.

Gandhar structure is a NNE-SSW trending structural nose with a south west plunge and straddles between Bharuch depression towards South East and Tankari depression towards North West with small fluid anomaly faults. Sands are deposited in distributary mouth bar/channel environment and sand entry was from North eastern and eastern side which grades into prodelta shale towards West. Sand bodies are separated by transgressive shale.

Gandhar is the biggest onshore oil field in India, wherethe oil is confined inmultilayer sand stone reservoirs designated as: GS -1 to GS -12 in Hazad member of Ankleshwar formationof middle Eocene age, and GS – 13 in Ardol member of Ankleshwar formation of Upper Eocene age.These reservoirs are separated by extensive shales and form structural cum stratigraphic trap within the western rising flank of Broach Syncline.Production from the field commenced in May 1986, and as of now, around 665 wells have been drilled including water injection wells to exploit the field. The field produces sweet oil, gas and condensate. At present, however, many wells are producing oil with high water cut, and in many cases with the support of gas lift. These wells have been identified by the Asset for undertaking RMT surveys to ascertain leftover Oil and Gas saturation,so as to make alternative completions and/ or plan for other exploitation strategy to enhance production and overall recovery.

The well GND # A was drilled in 1996 to produce oil from sand 12-A. Over the years the well contributed significant quantities of oil and gas before it started flowing with high water cut. RMT was planned to know the left over oil in GS-12A in the year 2011.RMT results in GND # A identified left over oil saturation in the top part of GS 12A sand. Prior to the RMT survey, the well was completed against interval 3145.5 – 3148.5m in GS 12 sand, which produced Oil with high water cut. Upon identifying leftover Oil saturation, perforation was confined only in the top part in the interval 3145 – 3147m (Fig.2&3), which is now producing 89.3 m3/d of oil with 66% water cut on gas lift.

The well GND # B was drilled in 2003 to exploit gas from 3B. However, the well was completed in upper sands to produce oil. On exploiting oil from sands GS-4, GS-5A and Gs-6A, the well started producing high water at different stages of completion. This well has produced 36512 tons of oil & 49.84 MMm3 of gas (cumulative).RMT was recommended to know the left over oil saturation in these sands and recomplete the well on assessment of the reservoirs units. RMT result in GND # B showed presence of hydrocarbons in GS-5A sand in the interval 2968.0 – 2969.8m. The rest of the sands were watered out. The well was recompleted in the interval 2967.5 – 2969.5m (Fig4&5), which produced Q liquid: 38 Cu m/ day and Q gas: 16000 Cu m/day through 10 mm bean with 11% watercut.

GND # C is a new well, where open-hole porosity logs were not recorded. In the absence of the porosity logs RMT was carried out in this well to know hydrocarbon saturation for further completion of the well in suitable reservoir. RMT result shows GS-4 sand is interesting. The interval 3158 – 3161m (Fig.6&7) in GS -4 was perforated, which flowed oil and gas through 6 mm bean.

In GND #D, RMT was carried out to see the residual saturation in different sands to recomplete the well. RMT result showed GS-3B depleted and only marginal interest is depicted in GS-11 sand in the interval 2907.5 – 2908.5m. In addition to interval 2907 – 2908.5m of GS-11, GS-4 sand in the interval 3007–3009m (Fig.8,9,10&11) was also perforated based on nearby well performance. The well produced water confirming RMT results.

The well GND # E was drilled in the year 1990 for oil production from GS-9 and GS-5C sands. After producing 148891 tons of oil and 55.37MMm3 of gas from GS-5c and 1,30,120 MT of oil from GS-9 the well ceased with high water cut. RMT was planned to know the left over oil in GS-5c and GS-9.RMT results show that both the sands are watered out (Fig.12,13) and the sands GS-6B & 6Ain the intervals 2900-2903 m 2887.5-2890m are hydrocarbon bearing. The well was recompleted in layer 6B only in the interval 2900 – 2903m (Fig.14&15). On perforation the zone produced100 m^3/d liquid with 84% water cut on gas lift.

APPLICATION IN ANKLESHWAR FIELD:

Ankleshwar field is located 15 km from Ankleshwar town and the field was discovered in 1960. The field is a part of Narmada Block of Cambay Basin and is spread over an area of 32.27 sq km. Commercial hydrocarbons were established in multi layered sand stone system. Production from the field started as early as 1961.

Efficacy of RMT in higher end of hydrocarbon saturation

Towards hydrocarbon end also RMT result in Ankleshwar field has been very fruitful for undertaking well recompletion. ANK # A is a good example. This well was drilled in 1990 to produce oil and gas from S3 and S4 sand units. After prolonged production till 2011, the well started producing with high water cut of 96%. RMT was planned to know the current hydrocarbon saturation in different sand units and complete the well in suitable zone. RMT in this well showed that S-1, S-2, S-3 and sub layers of S-4 are hydrocarbon bearing. Upon perforating interval 1155 – 1156m and 1168.5 – 1169.5m (Fig.16&17) the well became active through GLV's and flowed Q liquid: 34.55 Cu m/day through 10 mm bean with 87.62% technical water.

Efficacy in lower end of hydrocarbon saturation

Oil discovery in the shallow reservoir in one of the Ankleshwar well recently gave impetus to improve recovery from the declining Ankleshwar field. ANK # B was drilled in March 2011 to tap Oil from shallower sands. On testing the sand in the interval 124 – 127m, the well flowed water, which didn't affirm the expectations? RMT therefore was run in March 2011, to ascertain Oil saturation through the measurement of carbon/oxygen. This gave the opportunity to test quantitative values of saturation derived from cased hole measurement of RMT data, at least in one of the extreme end case when $S_w \approx 100\%$, with well established open-hole derived interpretation result.

RMT processed result is found complying fully with open-hole ULTRA processed result, and at the same time, found concurring to test result (Fig. 18&19).

Comparison of ULTRA and RMT Results

C/O derived Oil saturation values are in very close agreement with ULTRA derived Oil saturation values. This validates RMT derived Oil saturation values and establishes the robustness of technology.

The capture spectrum has not indicated presence of significant Gas saturation. Porosity values derived from RMT data are found to be in close proximity to open-hole density and neutron porosity values. Oil saturation values derived with inputs of RMT derived porosity values are in close agreement with saturation values derived with open-hole density-neutron data.

RMT RESULTS IN ADJOINING FIELDS:

Olpad Field:

Olpad field is situated about 16 km NW of Surat Town and was discovered in the year 1962 when Miocene sand produced gas in the second well of Olpad field. So far, 38 wells have been drilled in this field.

In Olpad field mainly three sands TS1, TS2 and TS3 are gas producers falling in different blocks within the same field. The well Olpad # A has been put on production from TS2 and ceased with high water cut. RMT has been carried out in the well under study to assess the present hydrocarbon saturation and take remedial actions for further completion.

RMT results in this well displayed TS-2 as totally watered out and TS-3 in the intervals 652.5 – 654.5m, 677.0 – 679.5m and TS-4 in the interval 627.5 – 629.5m and 634.0 – 637.5m as hydrocarbon bearing.

As TS2 is totally depleted (Fig.20&21), it was decided to complete the well in TS3. On perforating TS-3 in the interval 652.5 - 654.5 and 677 – 679m (Fig.22&23) the well produced 23,000 Cu m of gas through 5 mm bean.

CONCLUSIONS

RMT results all along have been found to testify production test data, which enabled fresh completion and putting the sick well back to active production stage.
Capture data is found very effective in detecting gas zones.

Oil saturation values obtained through open hole logs ULTRA derived result and through cased-hole RMT data are found to be in good agreement with each other.

The agreement of interpretation results emanating from two different technologies and its match with test results affirm the authenticity of the RMT derived results.

Porosity data derived from RMT is also in close proximity to open-hole density and the neutron values.

ACKNOWLEDGEMENTS

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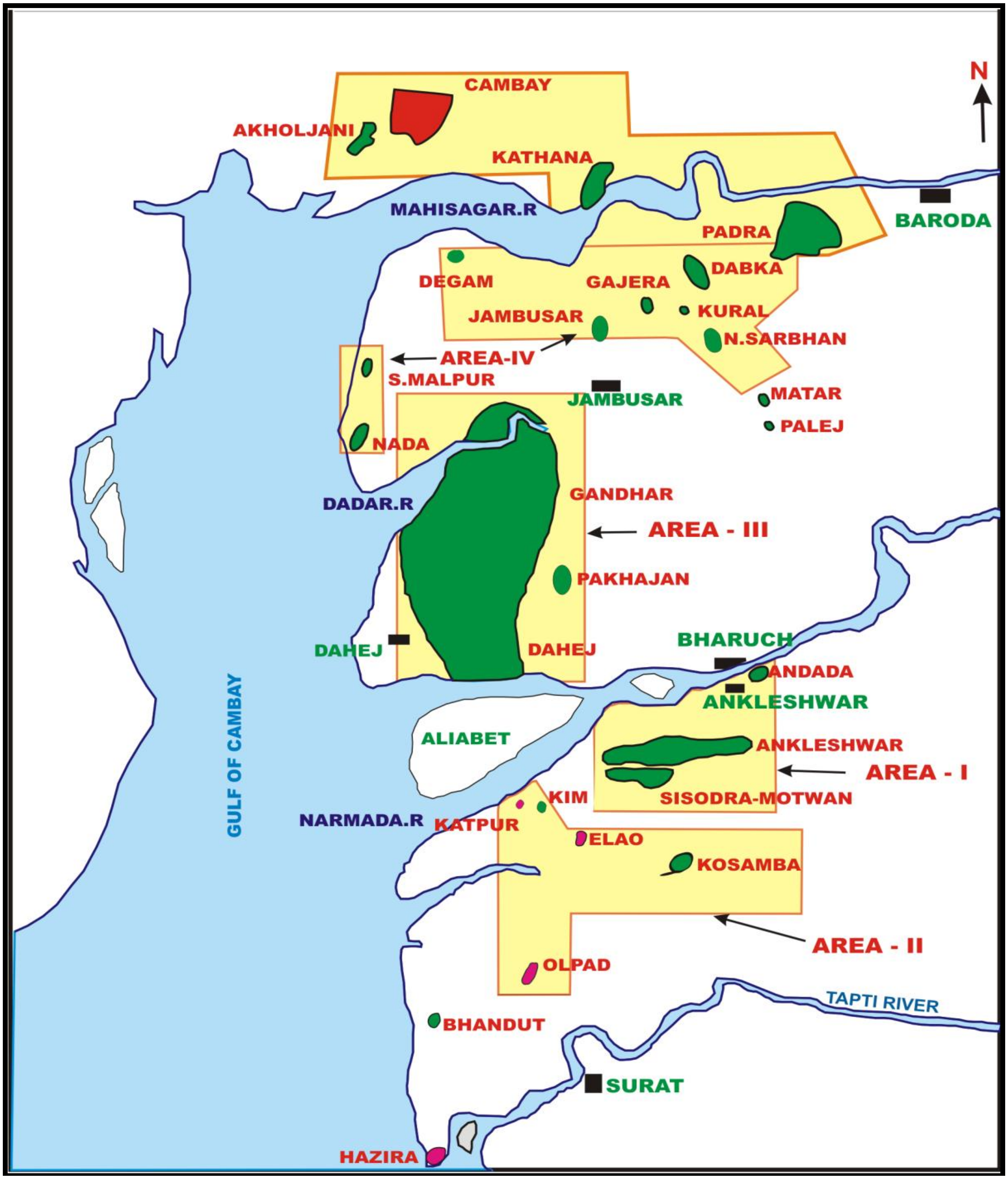
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Fig.1

Well: GND # A

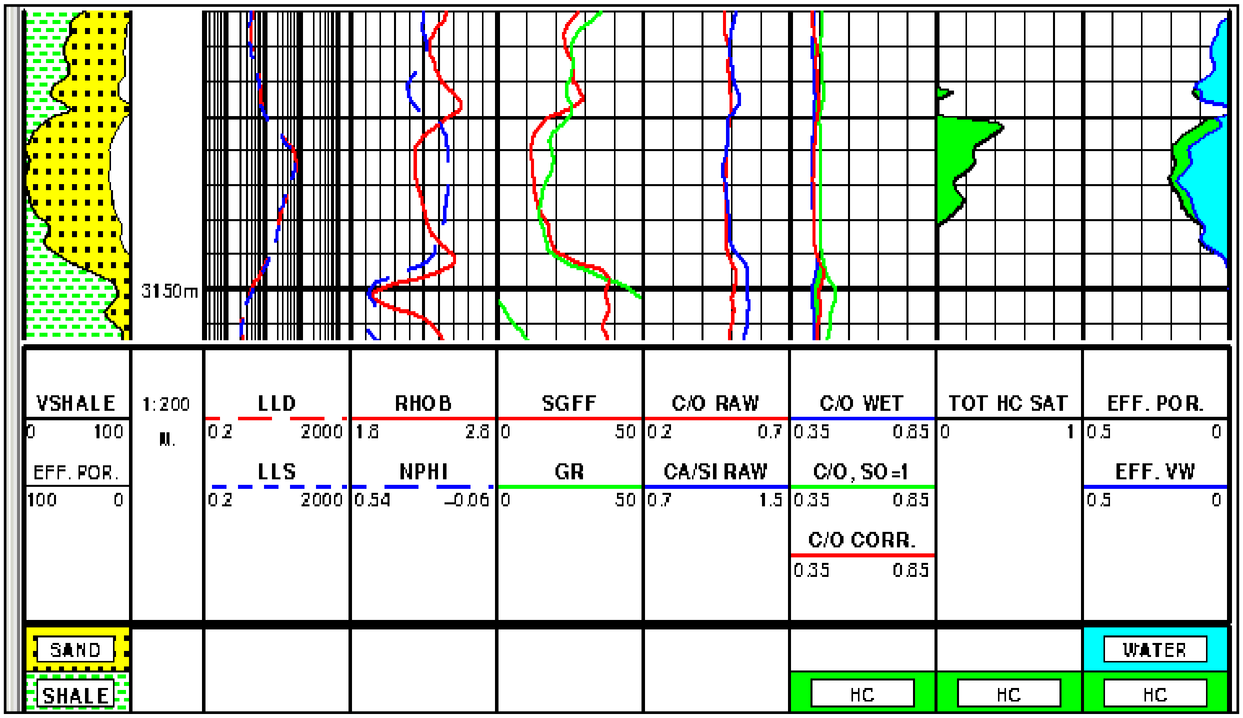

Fig.2 Carboxsat Processing Result

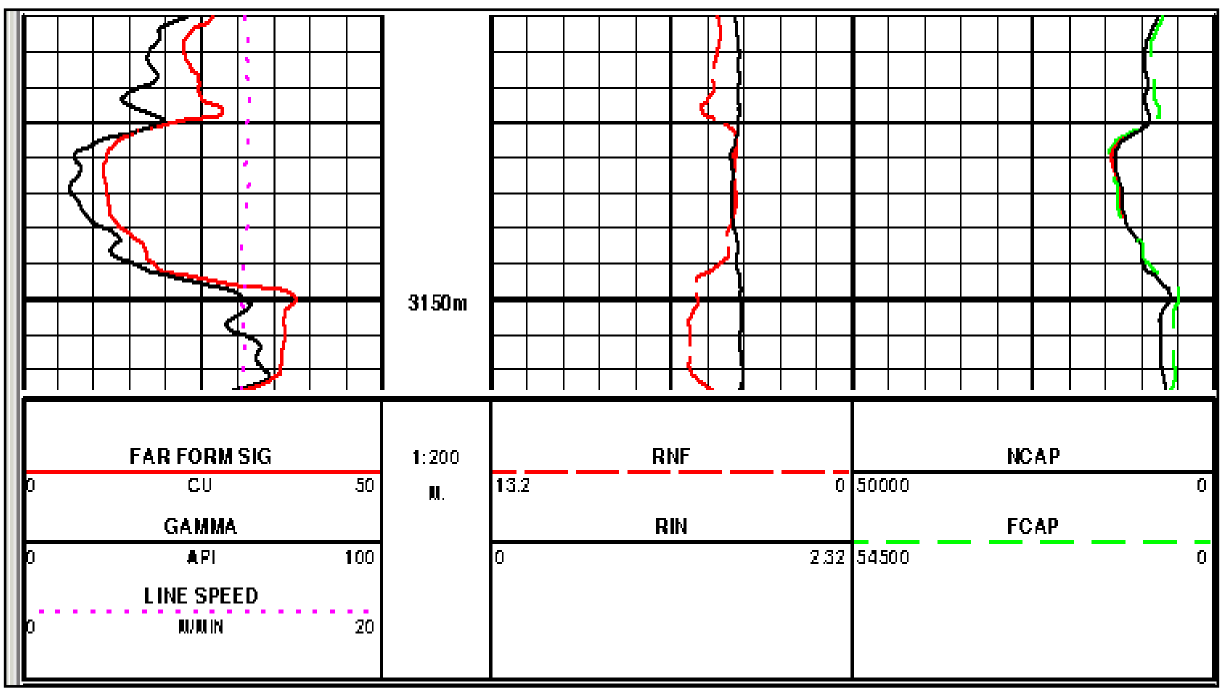

Fig.3 Sigma Processing Result

Well: GND # B

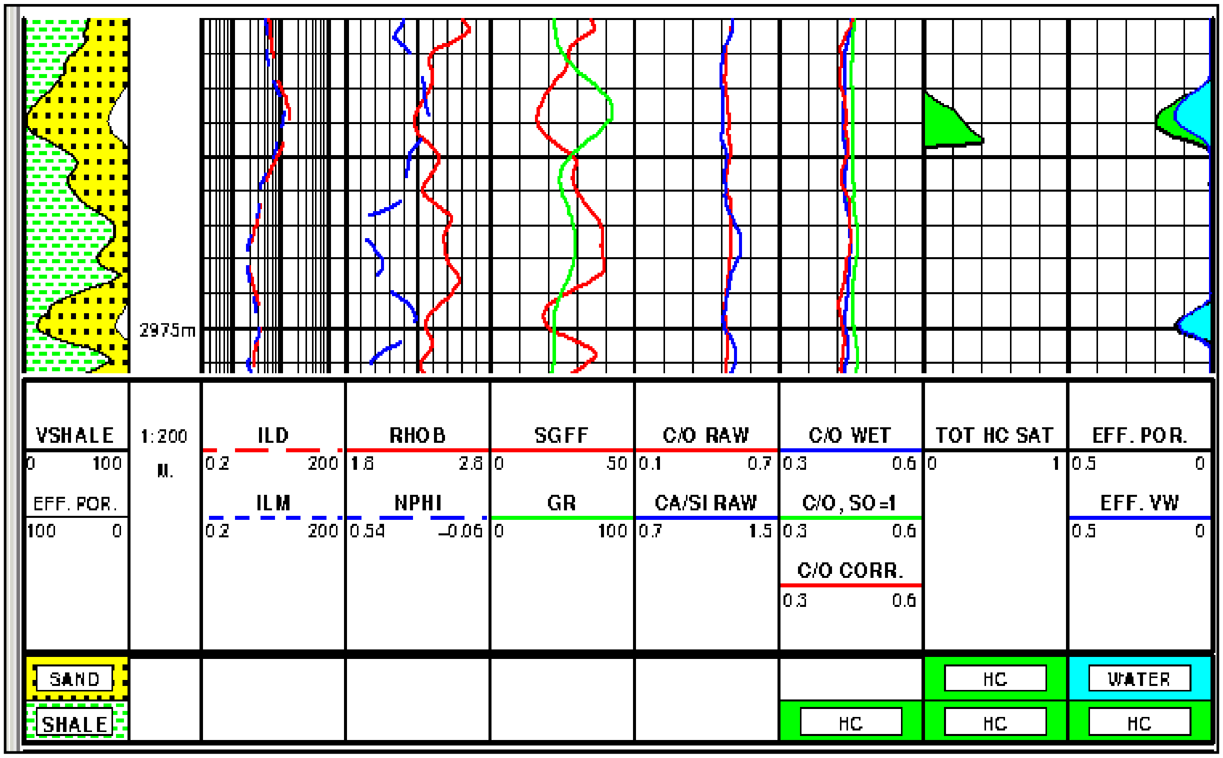

Fig.4 Carboxsat Processing Result

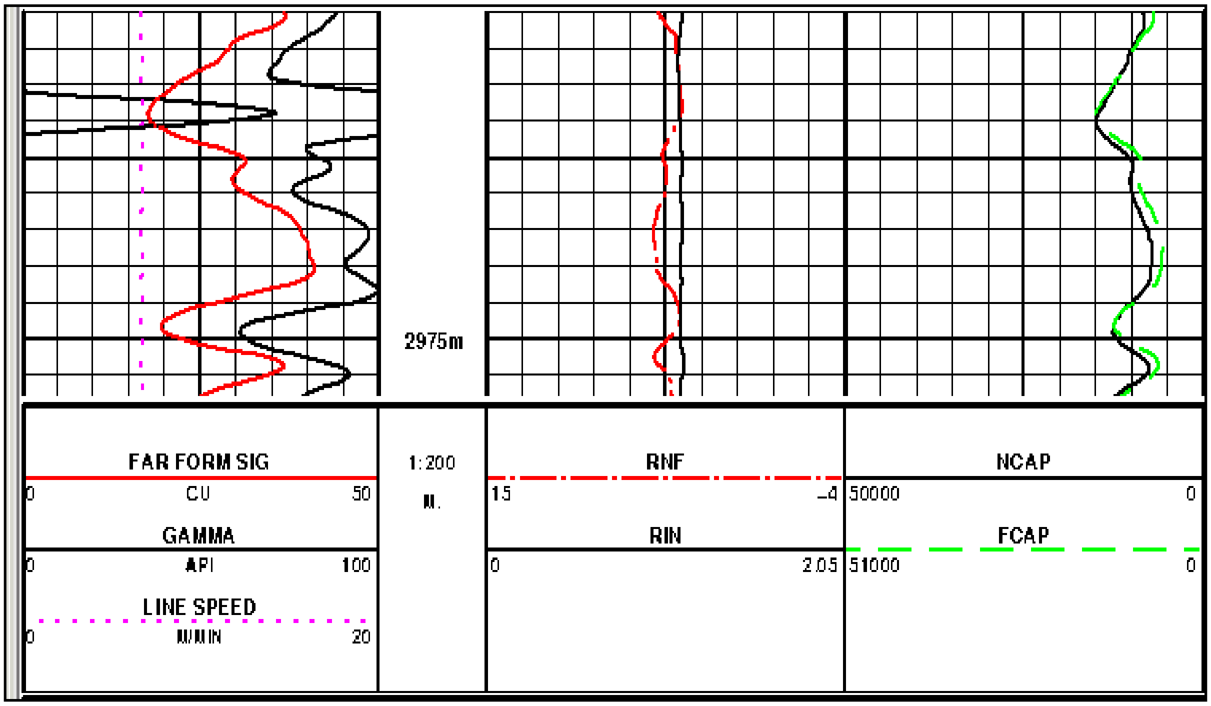

Fig.5 Sigma Processing Result

Well: GND # C

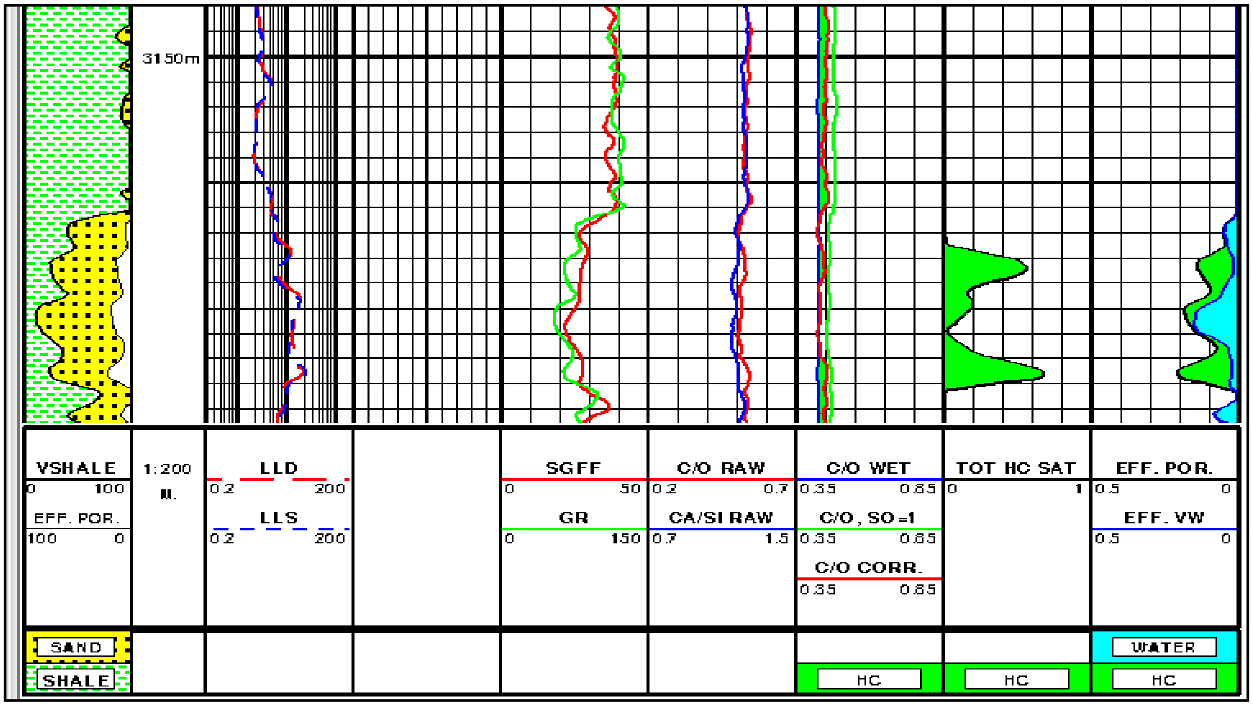

Fig.6 Carboxsat Processing Result

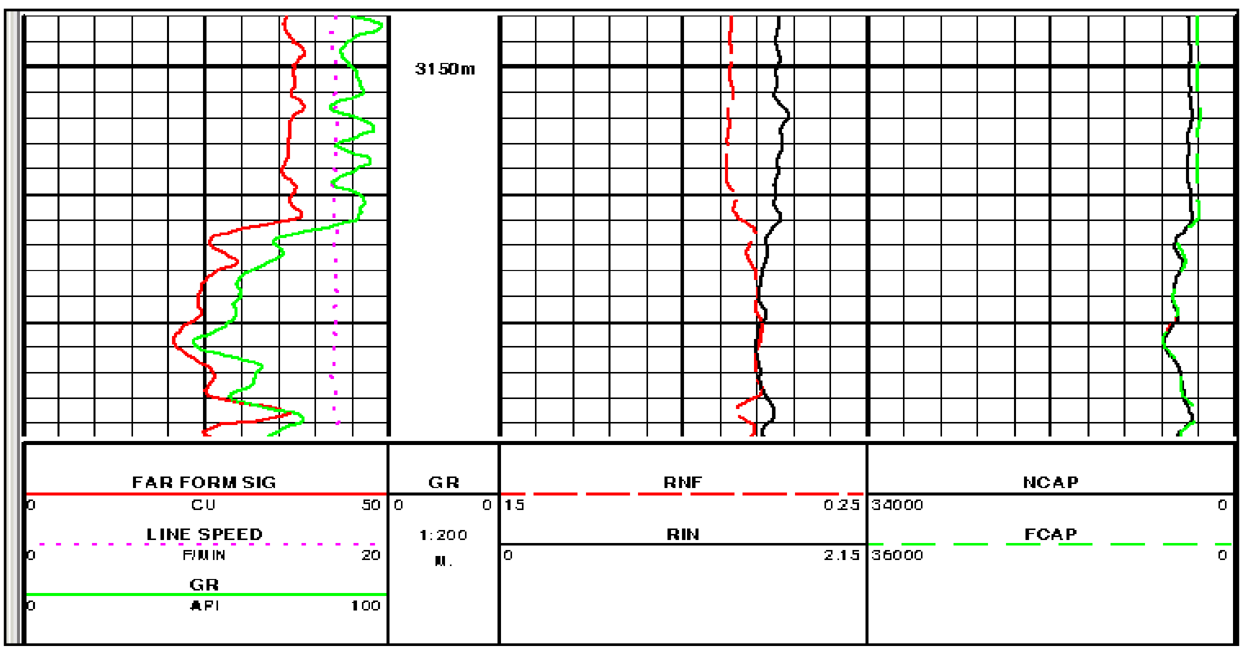

Fig.7 Sigma Processing Result

Well: GND # D

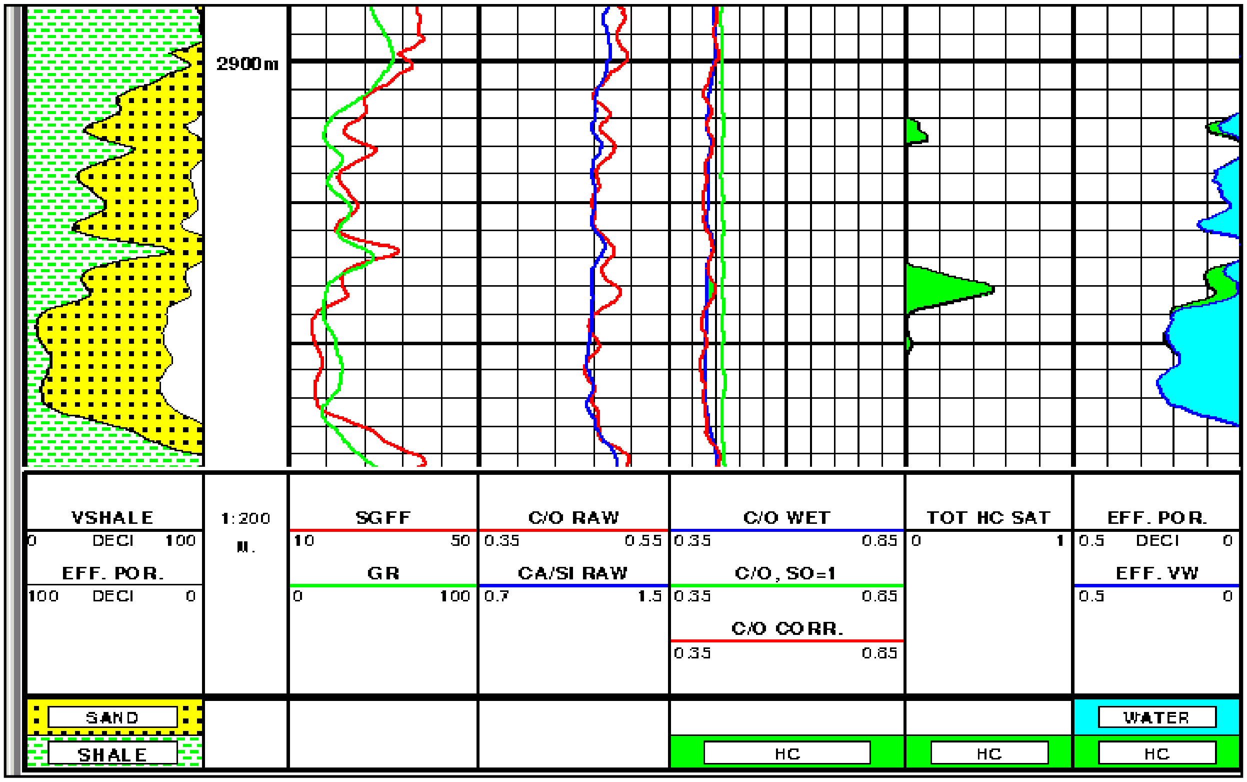

Fig.8 Carboxsat Processing Result

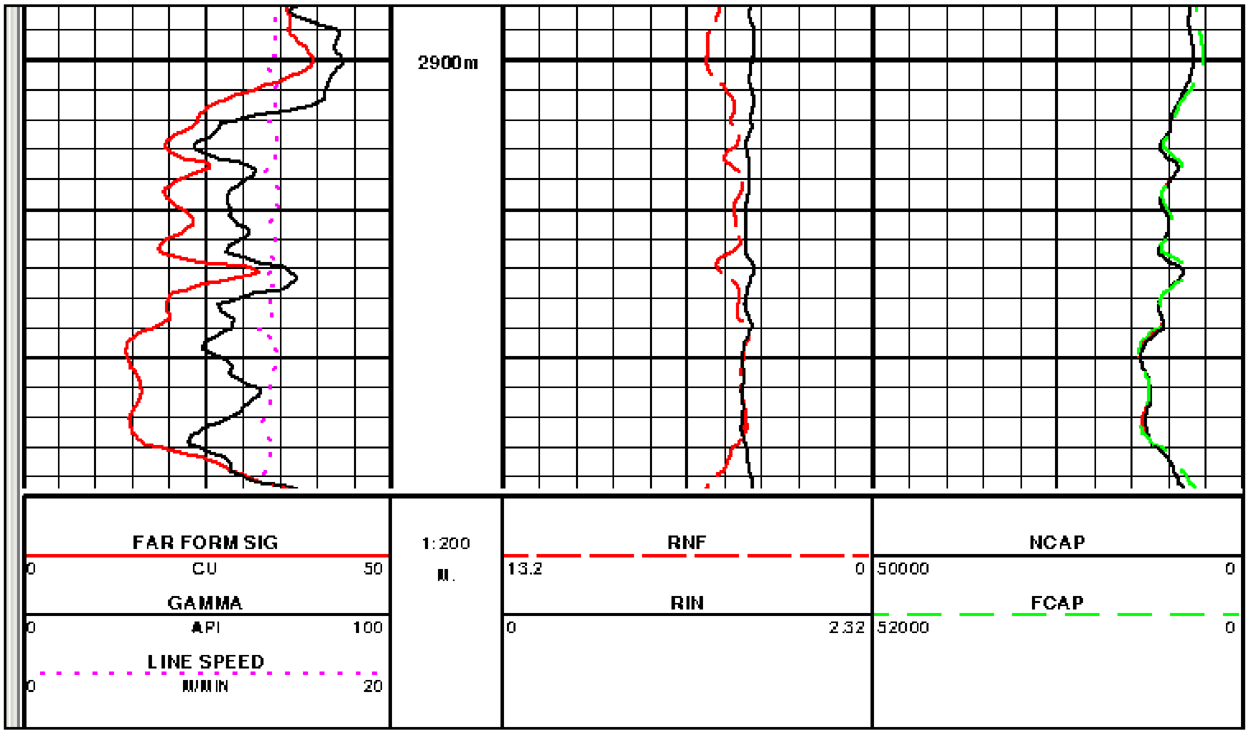

Fig.9 Sigma Processing Result

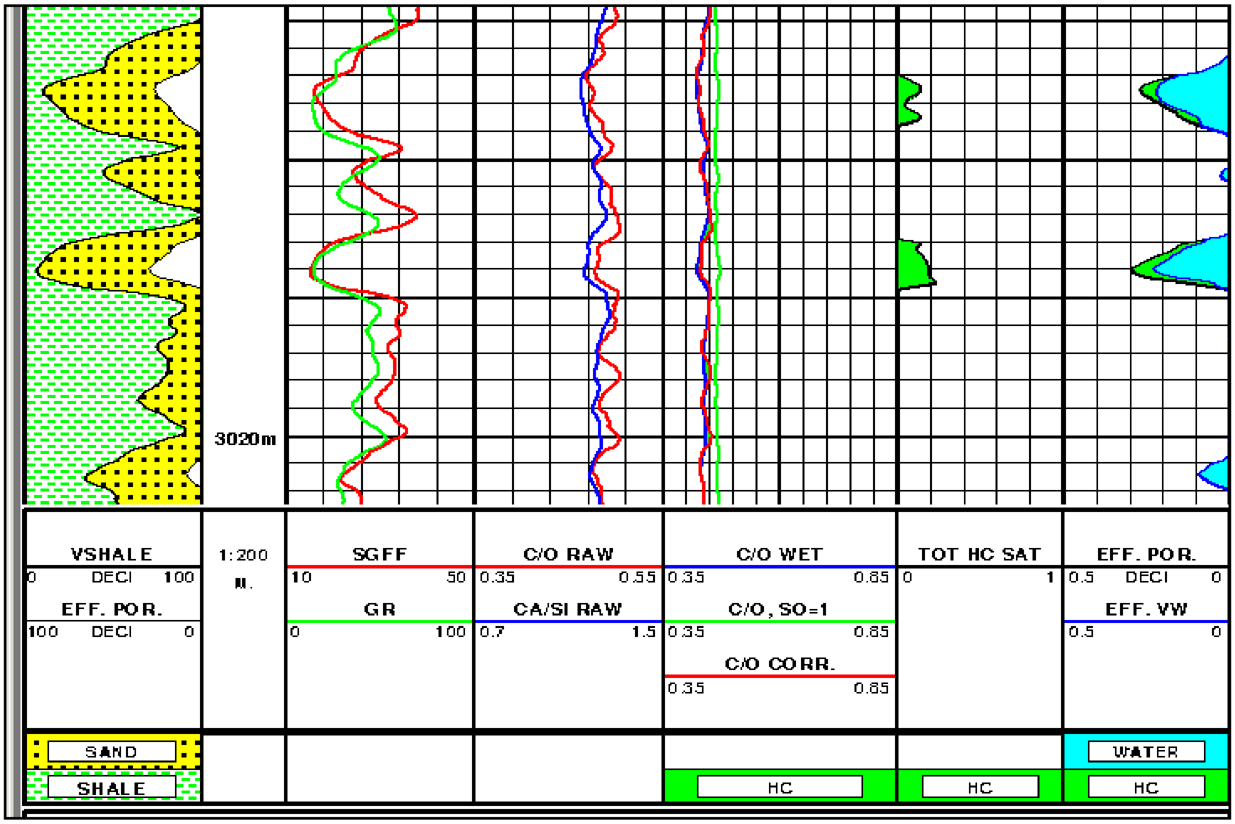

Fig.10 Carboxsat Processing Result

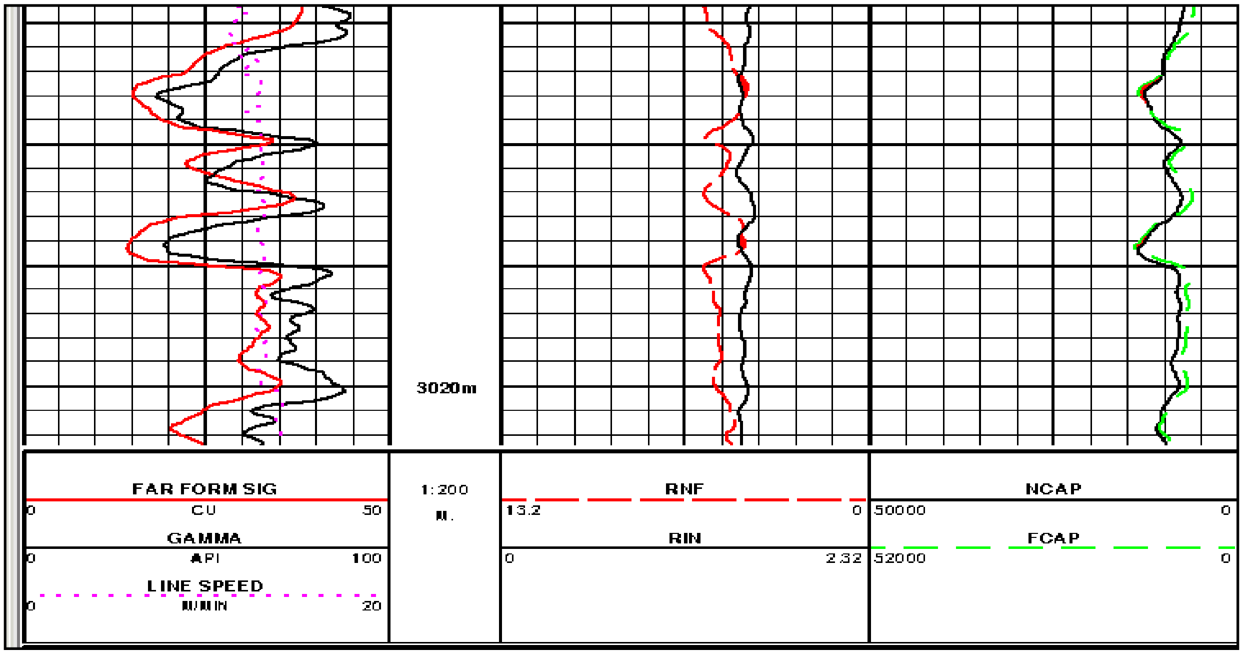

Fig.11 Sigma Processing Result

Well: GND # E

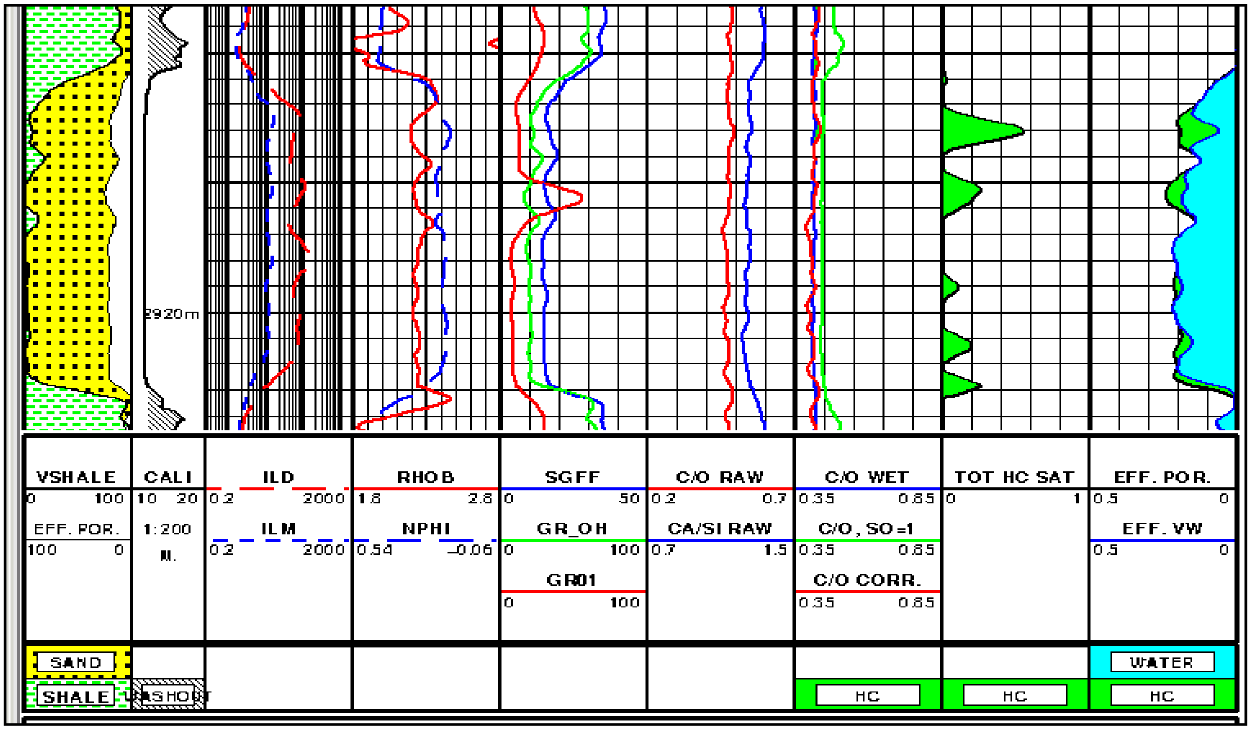

Fig.12 Carboxsat Processing Result

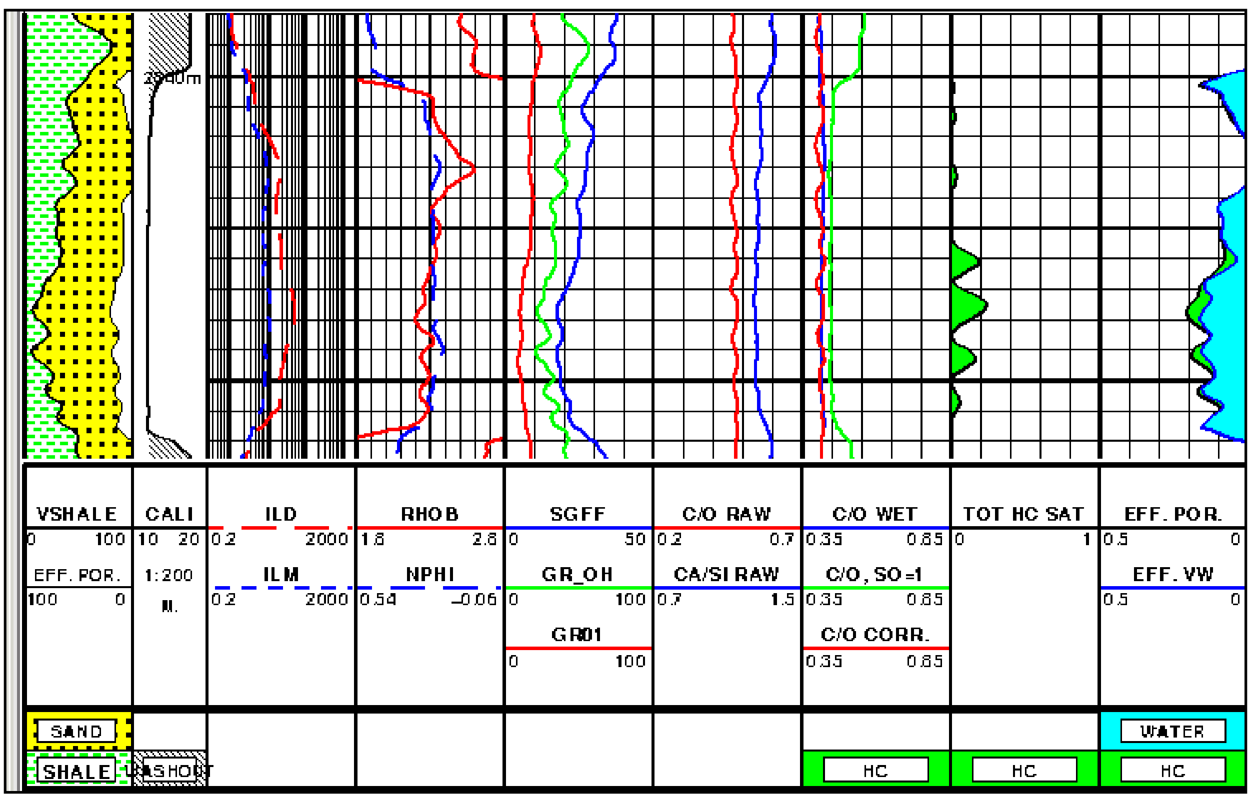

Fig.13 Carboxsat Processing Result

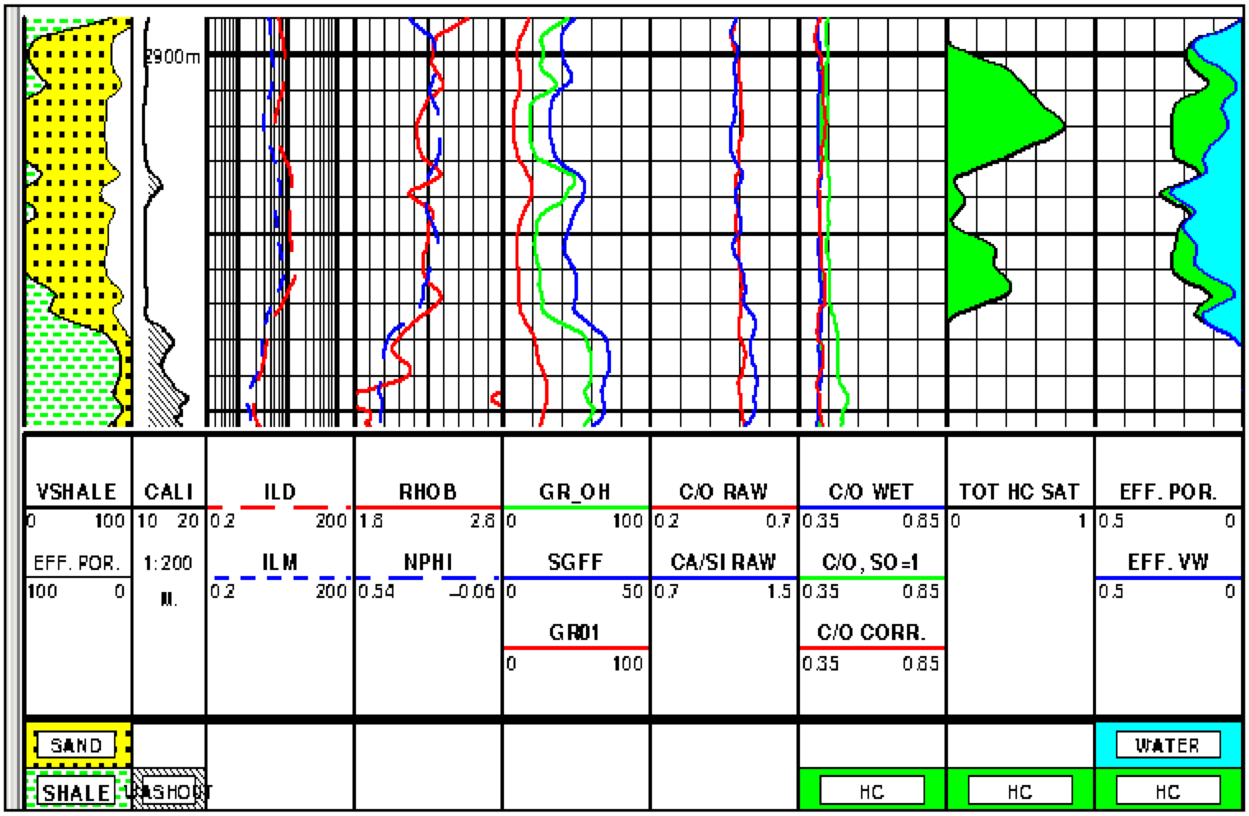

Fig.14 Carboxsat Processing Result

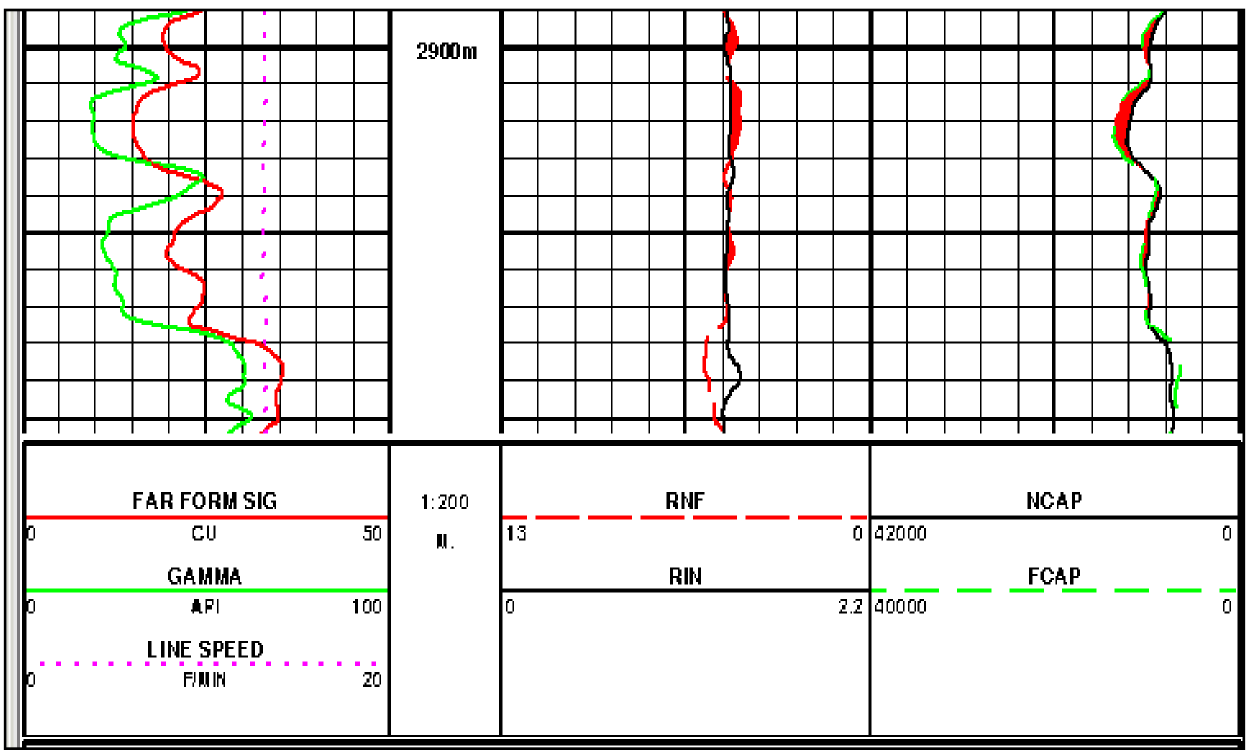

Fig.15 Sigma Processing Result

Well: ANK# A

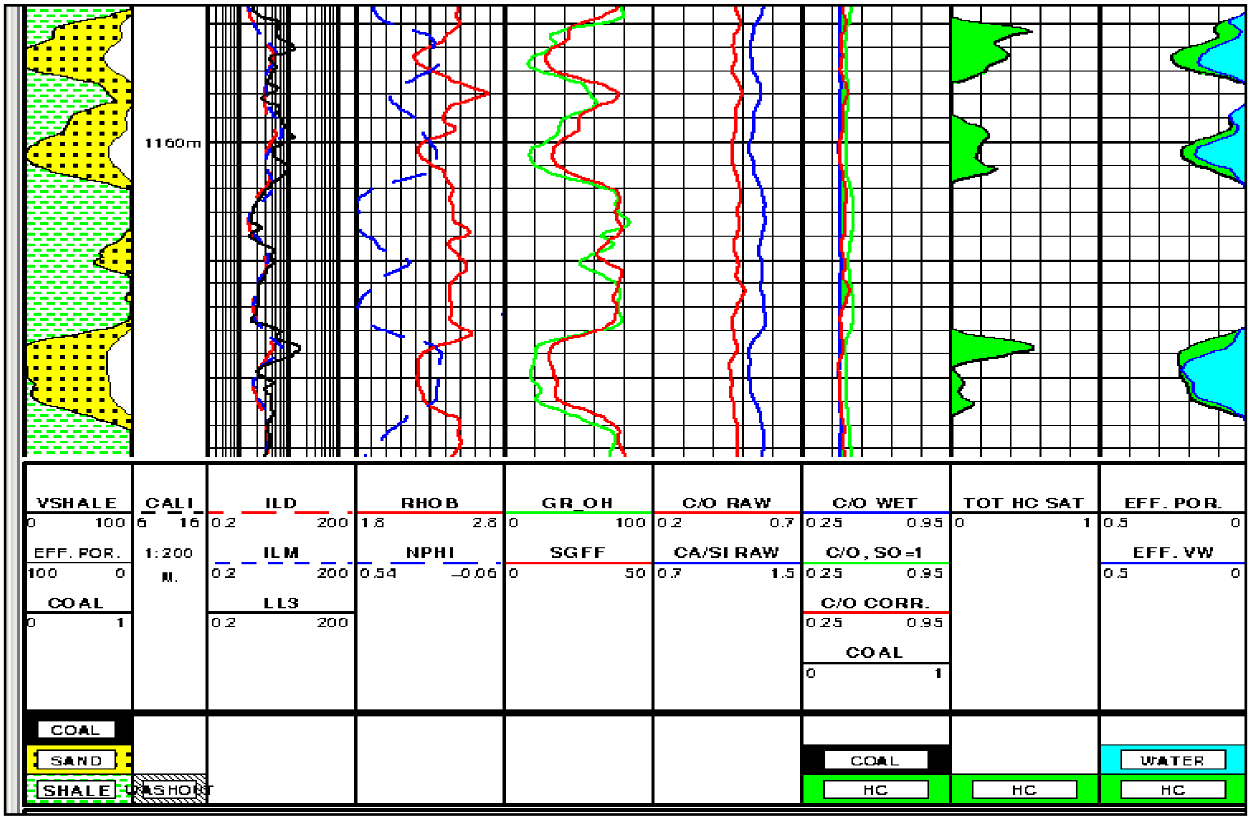

Fig.16 Carboxsat Processing Result

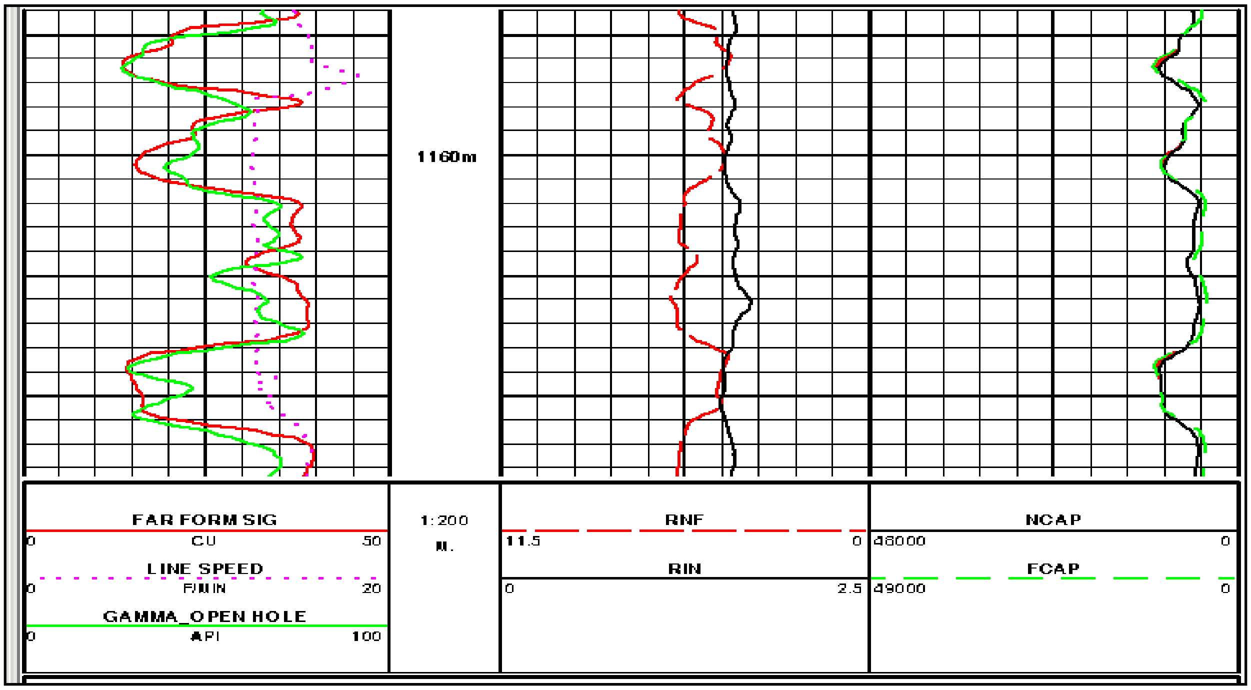

Fig.17 Sigma Processing Result

Well: ANK# B

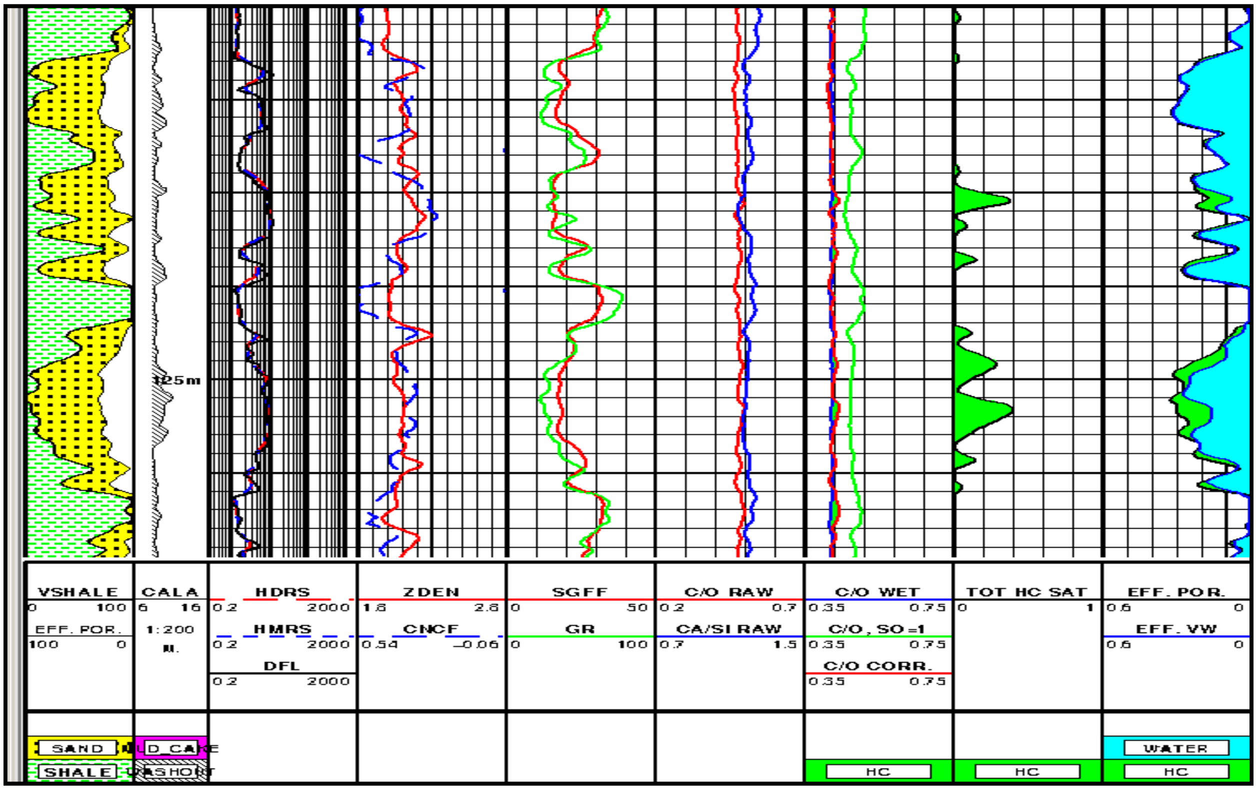

Fig.18 Carboxsat Processing Result

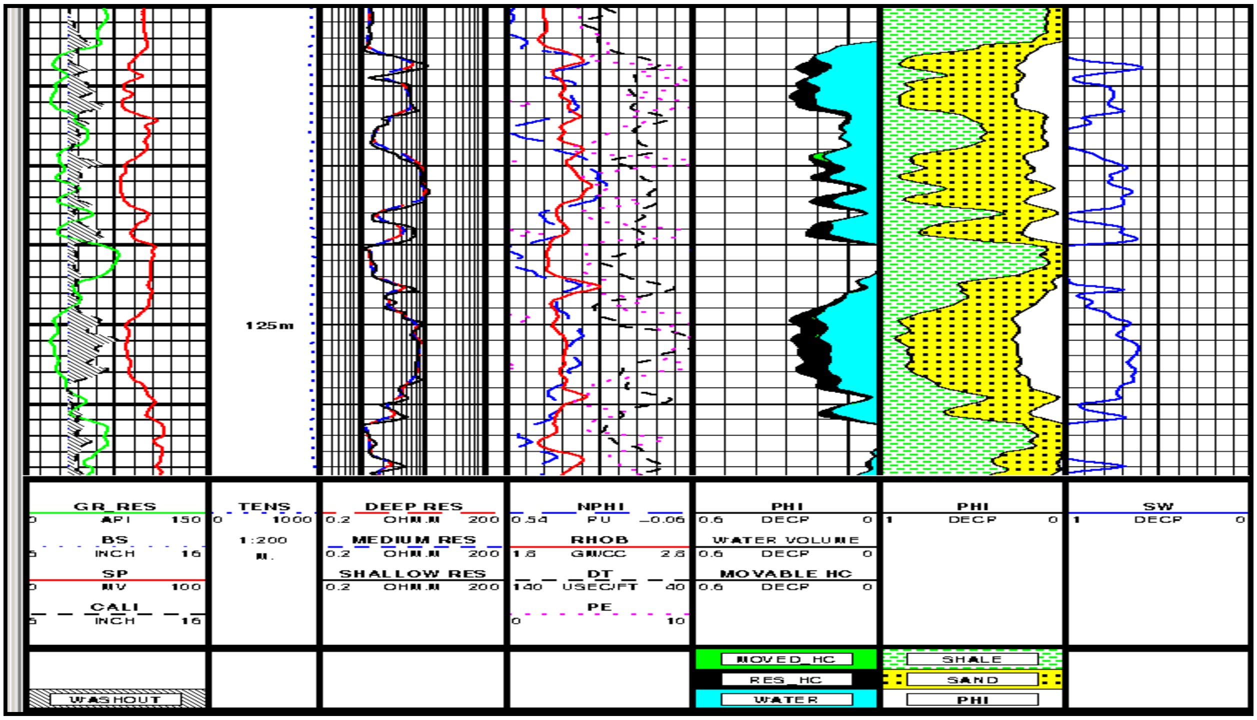

Fig.19 ULTRA Processing result

Well: OLPAD# A

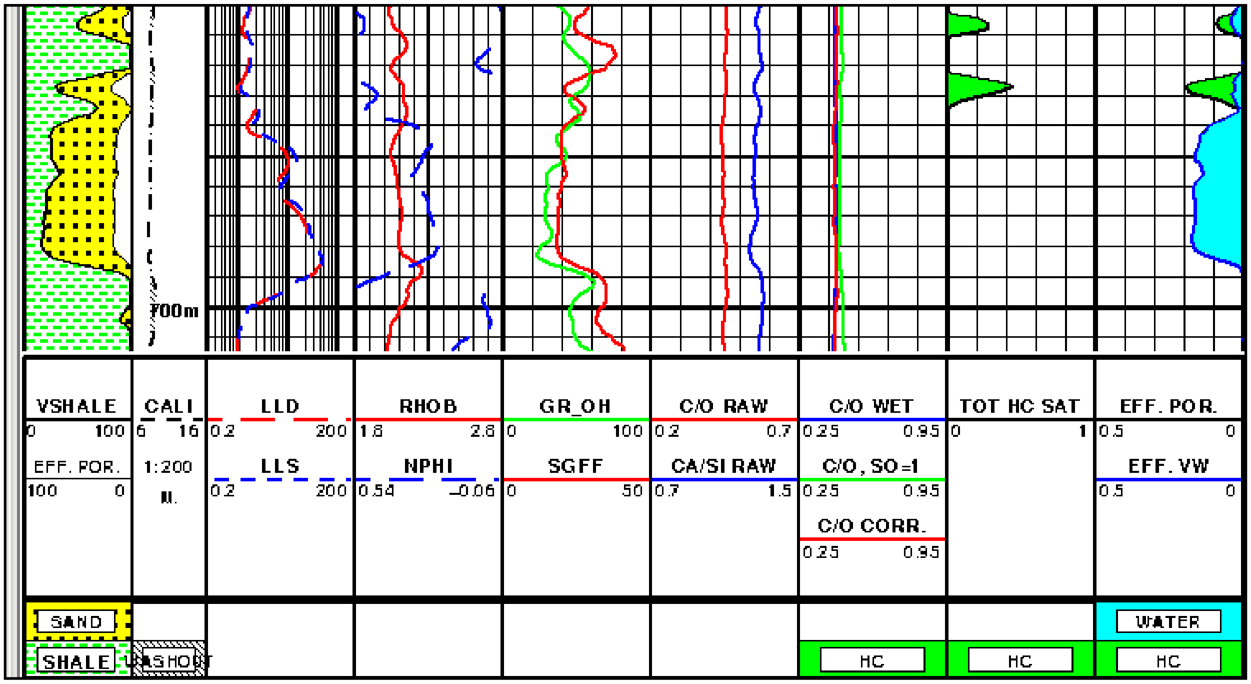

Fig.20 Carboxsat Processing Result

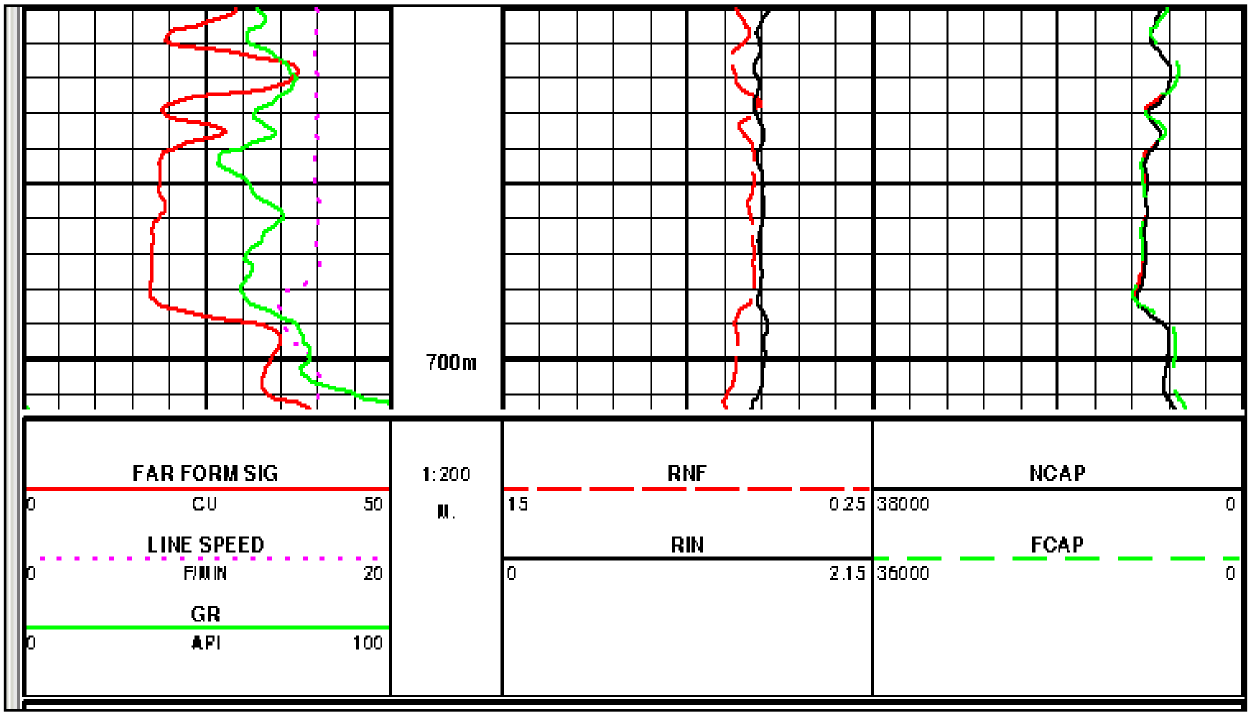

Fig.21 Sigma Processing Result

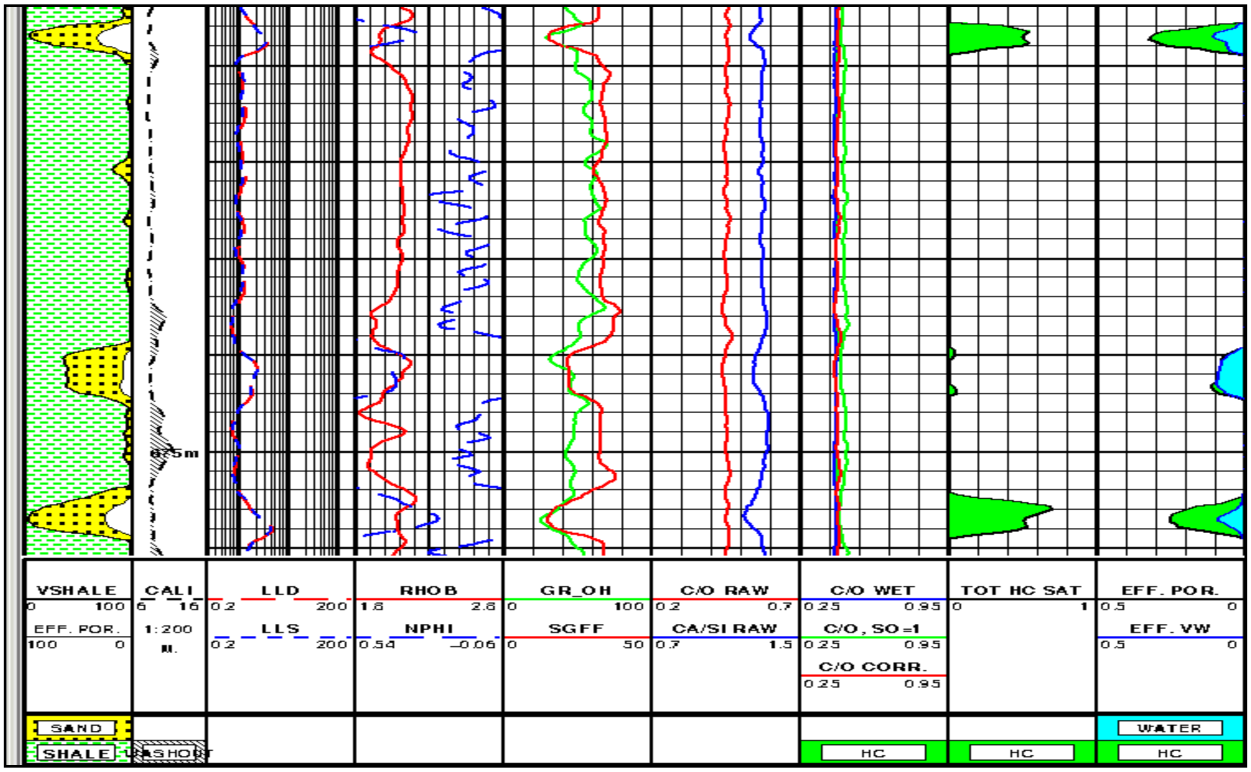

Fig.22 Carboxsat Processing Result

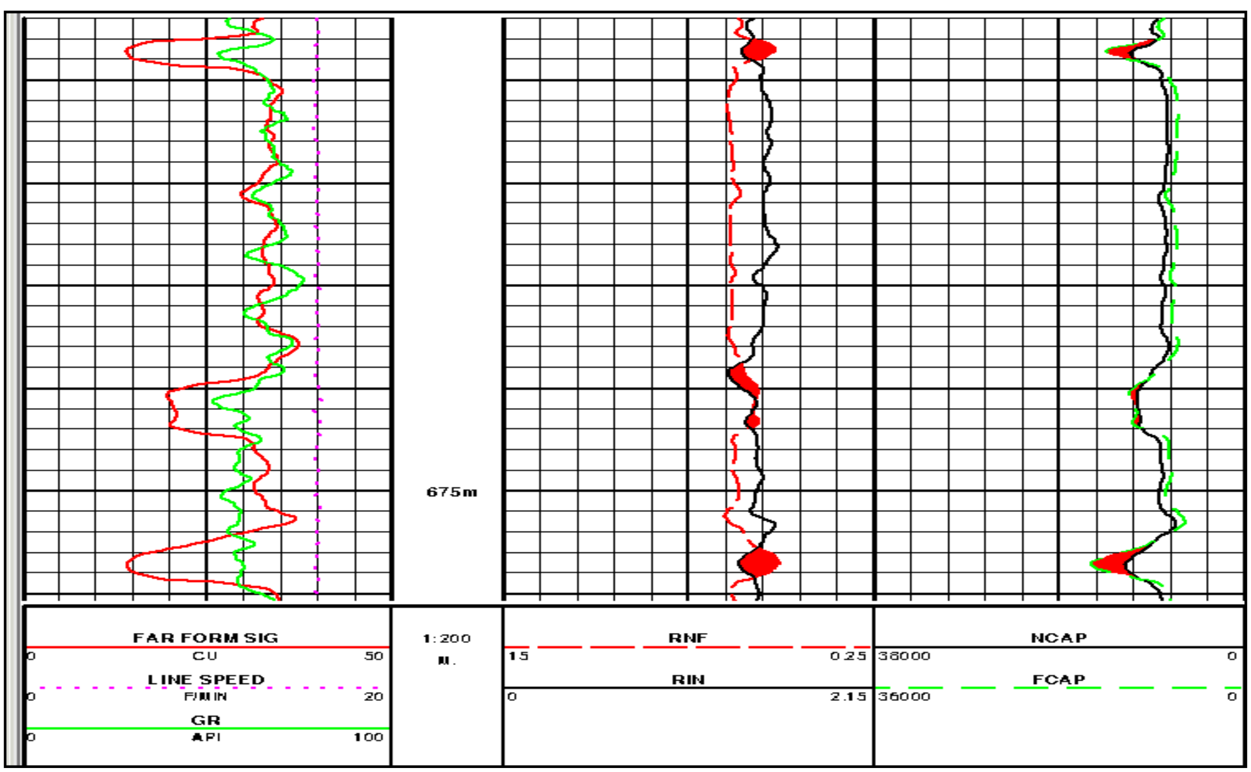

Fig.23 Sigma Processing Result