Reservoir Monitoring Through Cased Hole Formation Resistivity Tool: A Case Study from Sobhasan Complex Mehsana Asset, Gujarat India*

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Abstract

Enhancement of oil recovery in mature fields like the Sobhasan Complex requires close monitoring of reservoir pressure as well as hydrocarbon saturation with time. In comparison to the pressure, saturation in the reservoir has always been ignored. Knowledge of the variation of saturation with time helps in better understanding depletion of the reservoir and thus helps to determine better completion and perforation policies.

The Sobhasan Field is located in the Ahmedabad-Mehsana tectonic block of Cambay Basin and covers more than 40 km^2, extending 25 km to the north of Mehsana City and to Dholasan Village in the south. It is the second largest producing field of the Mehsana Asset. Sobhasan Field was discovered in 1968, and since then hydrocarbon has been exploited from multilayered reservoirs of Kalol, Sobhasan, BCS and Mandhali pay sands. Production from the Field started in 1969 at 25 tpd, and with continuous development of various oil pools and reservoirs, production from the Field peaked at 1767 tpd during 1991, but in the subsequent years had experienced a continuous decline in oil production; as of this date the Field is producing 1102 tpd. Increasing water cut in peripheral wells of the Kalol and Sobhasan sands is the major reason for decline in oil production, calling for reservoir monitoring through a better and improved technology. In this regard, Cased Hole Formation Resistivity (CHFR) tools have been used to understand the movement of the oil-water contact (OWC) and identify bypassed oil, and thereby the extent of depletion of the reservoir. Study reveals the movement of the OWC, which helps carry out water shutoff jobs and review the perforation policy adopted earlier.

The case study presented in this paper describes successful water shutoff operations in two wells of the Sobhasan Field from the Kalol and Sobhasan pays; encouraging results were achieved with substantial decrease in water cut and increase in oil. Studying these wells

not only resulted in net oil gain, but also helped determine better perforation and completion policies for the other wells completed in these sands.

In this paper, determining resistivity behind casing, acquisition and time-lapse formation evaluation to monitor present saturation profiles are discussed in detail. Comparison between the original and present water saturation immediately detects the depleted zones and the degree of depletion across perforated intervals. This is considered an indication of a rise in oil-water contact or lengthening of the transition zone.

Introduction

Hydrocarbon saturation is always vital to understanding the dynamic condition of a reservoir, especially in matured and depleting reservoirs. Time-lapse saturation contrast helps to assess the movement of the OWC, the extent of depletion of a reservoir and identification of bypassed oil. However, the cause behind a change in saturation needs to be confirmed before deciding on a strategy for further exploitation. To confirm the cause, WOR and WOR' diagnostic plots were used. Analysis of these curves ascertain the need to acquire Cased Hole Formation Resistivity (CHFR) logs. Study reveals the movement of OWC by comparing CHFR logs with open hole logs and thereby calculate the extent of depletion. Subsequently, it helps to carry out water shutoff jobs and review the perforation policy adopted earlier. In addition, this study also suggested its implementation for the long run of a field, considering its realized gain in oil production and improvement in recovery. This paper presents the case study of wells in the Kalol and Sobhasan sands of the Sobhasan Field. The Sobhasan Complex comprises Sobhasan, South Sobhasan, Mewad, South Mewad, West Sobhasan and Kherwa fields.

Regional Geology

The Sobhasan Complex lies in the Mehsana-Ahmedabad tectonic block of Cambay Basin, is one of the most prolific oil producing onshore fields in India, and occurs in a narrow elongated rift graben (Figure 1). The Mehsana Horst is a prominent feature in the northern part of the block and divides the block into eastern and western depressions. The Mehsana Block, the northern block of Cambay Basin, is bounded by Kutch Uplift in the west and the Aravali Hills in the east. The Cambay Basin is a north-south trending rift. The northern part of Cambay Basin is mainly affected by extensional tectonics, the major structural element which divides the main block into two distinct regimes with a series of parallel horsts and grabens in the eastern part and a major depression in the center with prominent eastern and western rising flanks. Two major NE-SW trending transfer faults form the northern and southern boundaries of the Mehsana Block. The Sobhasan Structure is a doubly plunging anticline with numerous local lows and highs of varying trends from NW-SE to NE-SW with structure building faults trending north-south. The Sobhasan Structure is mainly producing from Kalol, Sobhasan, BCS and Mandhali sands. Here, case studies of wells completed in Kalol and Sobhasan sands are discussed in detail.

Reservoir Performance and Analysis

The Kalol Sands are developed between two prominent shale layers, the Tarapur Shale and upper tongue of Cambay Shale, and is characteristically developed in the South Sobhasan and Mewad areas and mainly deposited in a fluvial environment. Six oil bearing sands have been identified, from top to bottom KS-I to KS-VI, with KS-V and KS-VI as the main producers. Cumulative production from these pay sands constitute 24% of OIIP. In spite of higher cumulative production, the average reservoir pressure remains stabilized at around 120 Ksc from an initial pressure of 128 Ksc due to very strong aquifer support (Figure 2).

Field Block of the KS-VI Sand contributed the major oil production of the Sobhasan Complex in the past. This block is known for its permeability on the order of 800 to 1200 md and viscosity less than 4 cp. The pressure of this block is stabilized at 120 ksc due to large aquifer support. The peak production from this block was 540 tpd in 1991 with 5 wells. At present, the block is producing oil at an average rate of 62 tpd with 60% water cut through 9 producers. The recovery is around 21% out of total OIIP of 7.04 MMt (Figure 3). Sobhasan Main pay is the Kadi Formation, developed between upper and lower tongues of Cambay Shale, and consists of sand, shale and coal layers. Two massive coal seams are present, one at the top of lower tongue and another at the bottom of the upper tongue, and are used as markers for correlation. Sobhasan pay sands are fluvial to marginal marine sediment deposited in a lower deltaic regime with sediment input mainly from the north. Sobhasan pays are divided into four pay units, SS-I (SS-IA, SS-IB, SS-IC), SS-II (SS-IIA & IIB) and SS-III and BCS sands which are producing under mixed drive to depletion drive. For these pay sands, initial reservoir pressure has declined from 143 Ksc to around 80-100 Ksc. The pressure scenario shows a partial aquifer support from the edge water drive. OWC is seen in some of the wells of the block at 1363.5 m. To present, 0.39 MMt of reserves have been exploited out of a total of 1.87 MMt of OIIP. The recovery is 21%.

Measurement Theory and Methodology

Similar to an open hole log, the CHFR tool is like a laterolog device where the resistivity is calculated by measuring voltage that is generated by injecting current into the formation and the resistivity computed when the amount of the current and the voltage drop is measured. However, in the cased hole, conductive casing restricts the current to penetrate into the formation. Thus a low frequency current with high skin depth could leak into the formation and this leakage current measurement helps to determine the resistivity of the formation. Before calculating the saturation of a depleted zone, the CHFR log is compared with the open hole log of non-depleted zones. After matching the two logs, the general procedure is to determine the lithology, porosity and saturations from open hole logs.

Further saturations of the depleted zone are calculated by finding resistivity (Rt) from the CHFR tool and keeping other parameters, like volumetric information of matrix, the same as the open hole log. The extend of the depletion can be determined by:

$$\text{CHFR (Extent of Depletion)} = \sqrt{(Rt(CHFR)/Rt(\text{Open Hole}))}$$

where Rt(CHFR) is the resistivity of the formation through CHFR and Rt(Open Hole) is the resistivity of the formation from open hole logging. Thus for analyzing CHFR tool data, we make the assumption that the volumetric condition of the matrix does not change with depletion of the reservoir. Secondly, substantial changes in salinity of the reservoir makes the analysis of resistivity a bit complex. The extent of depletion of the reservoir is calculated by taking the ratio of resistivity in open hole to cased hole.

Case Histories

Case 1: Water Shutoff in Kalol Sand in Sobhasan Fields

Well X is located in the South Sobhasan Field of the Sobhasan Complex. The well was drilled in early January, 1993 in the crestal part of the KS-VI sand for the exploitation of undrained oil. Open hole logs indicated KS-VI developed in the interval 1269-83 m with an OWC at 1279 m. Accordingly, the interval 1270-1274 m was perforated (5 m above the OWC). Subsequently, to Aug, 2010 the well has produced 99,000 Mt of oil (Figure 4). Decline in the oil rate along with high water cut was observed in Nov, 2009 which identifies the present oil level against the perforated interval. To understand the cause of increase in water cut, WOR and WOR' diagnostics curves (Figure 6) are plotted which shows the coning effect. For minimizing the effect, an X-linked polymer job followed by CSQ job were carried out in the opened interval 1270-1274 m.

Subsequently, CHFR was acquired to determine the current level of saturation against the perforated interval, movement of OWC, and unswept oil (if any). The log was analyzed and shows a good match in non-reservoir zones. Depletion of the top perforated interval is comparatively less than the lower perforated section and the present day oil saturation is lesser in the lower zone. It could be readily identified that the lower perforation is the main contributor of water. OWC was seen at 1276 m, which shows a rise of 3 m compared to the open hole logs. Further the extent of depletion is determined and shown in track. As depletion occurs, the CHFR depletion indicator should be less than one as indicated. On the basis of analysis of log, the interval 1270-1272 (2 m) was perforated. Results showed an increase in oil from 3 to 13 tpd and decrease in water cut from 80% to 40%. To present, around 2200 Mt of oil has been realized. On the basis of this well, current perforation policy has been determined for further exploitation of the KS-VI sands of this block.

Case 2: Water Shutoff in Sobhasan Sands of Sobhasan Fields

Well Y lies in the South Sobhasan Field and was completed in Sobhasan-IA+IB sands. The well was put on production in 1990 (Figure 5). Initially on the basis of open hole logging, the sand thicknesses of Sobhasan-IA (5 m), Sobhasan-IB (10 m), and Sobhasan-IC (6.5 m) were determined. Intervals 1425-1429 m and 1436-1444 m were perforated with initial oil production of 18 tpd with 40% water cut. Since then, it has cumulatively produced around 39,400 Mt of oil. Before free water was reported in April, 2008, this well was producing at 4 tpd with 85% water cut. Again, the analysis was performed using WOR and WOR' diagonostic plots (Figure 7) which show a coning effect with late channeling. Subsequently, CSQ was carried out in intervals 1425.0-1429.0 m and 1436.0-1444.0 m and USIT followed by CHFR was acquired. The CHFR log shows a good match with the open hole log in non-depleting zones and shows saturation in zone 1424-1428 m and 1454-1458 m. These intervals were perforated and resulted in revival from nil to 9 tpd presently. To present, around 2600 Mt of oil has been realized from this well. After observing this performance, water shutoff jobs were carried out in nearby wells in this block.

Conclusions

The Cased Hole Formation Resistivity measurement technique has been implemented successfully for reservoir management in the Sobhasan Complex area. CHFR evaluation helps to better select completion zones, thereby enhancing oil recovery from the reservoir. Monitoring through WOR and WOR' diagnostic plots provide greater understanding of the cause of depletion of the reservoir. This technique may be used to better understand the dynamic conditions of a reservoir.

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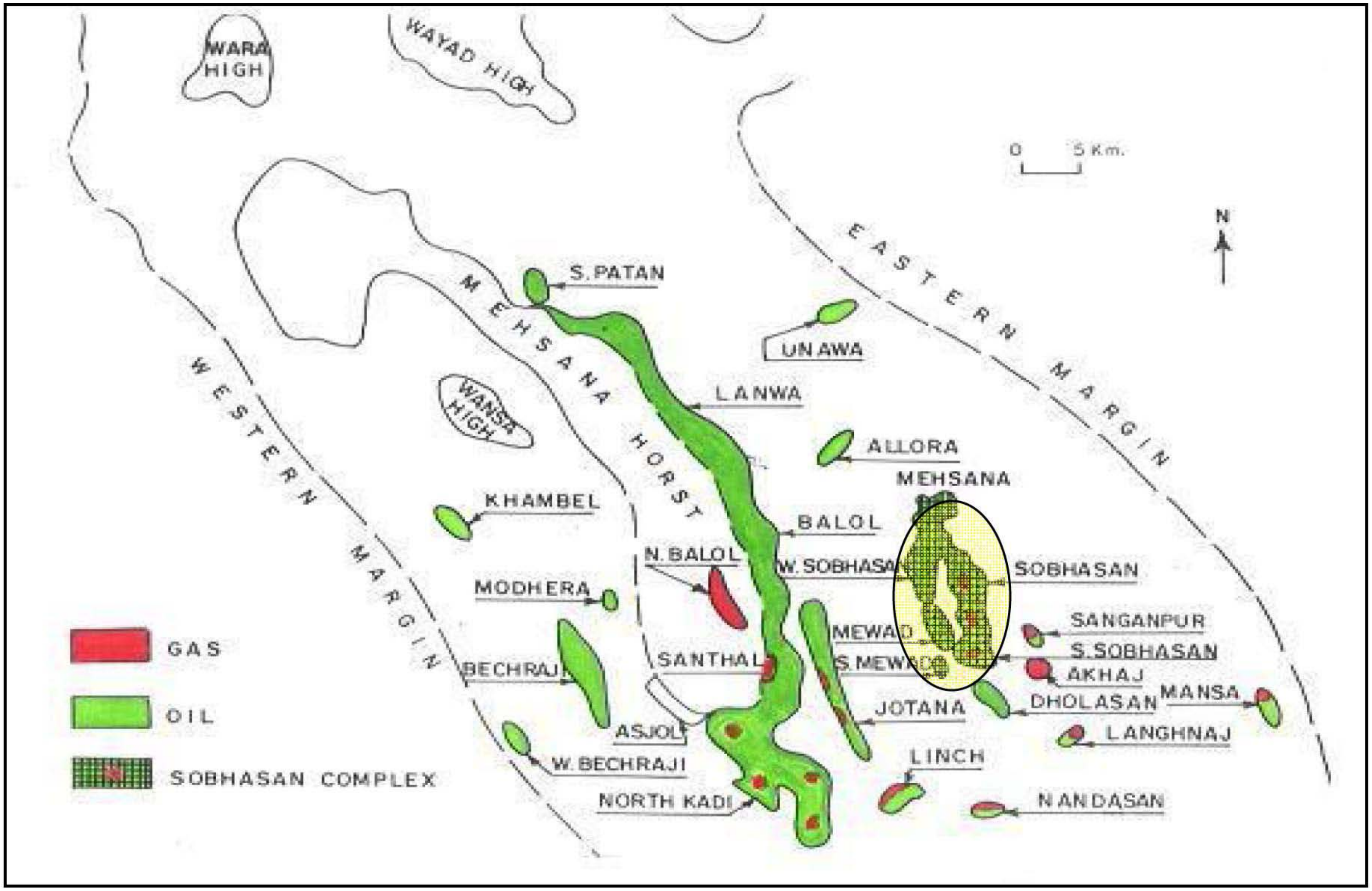

Figure 1. Tectonic map of Sobhasan Complex and adjacent fields of Mehsana Asset.

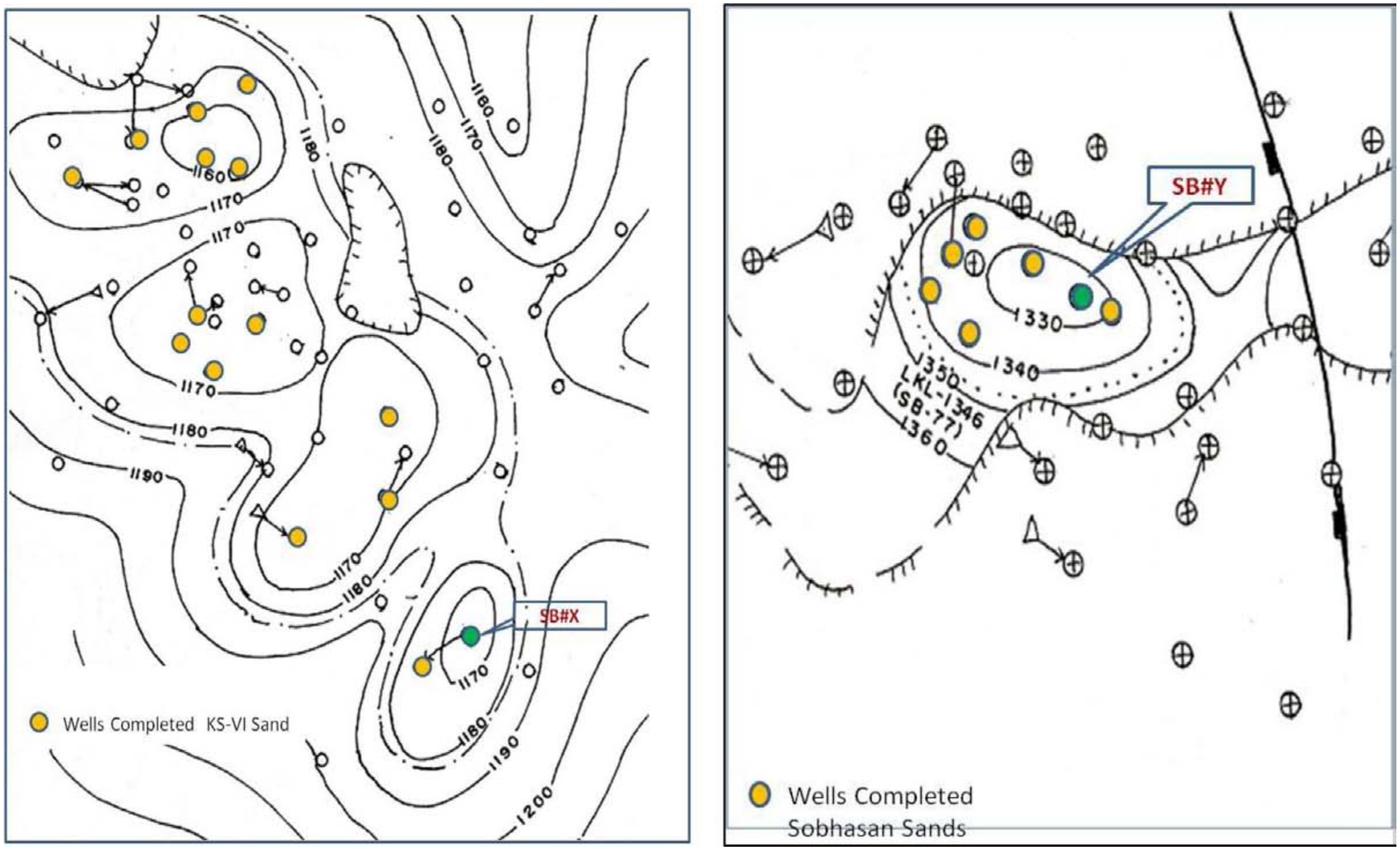

Figure 2. Structure contour map on top of KS-VI and Sobhasan sands.

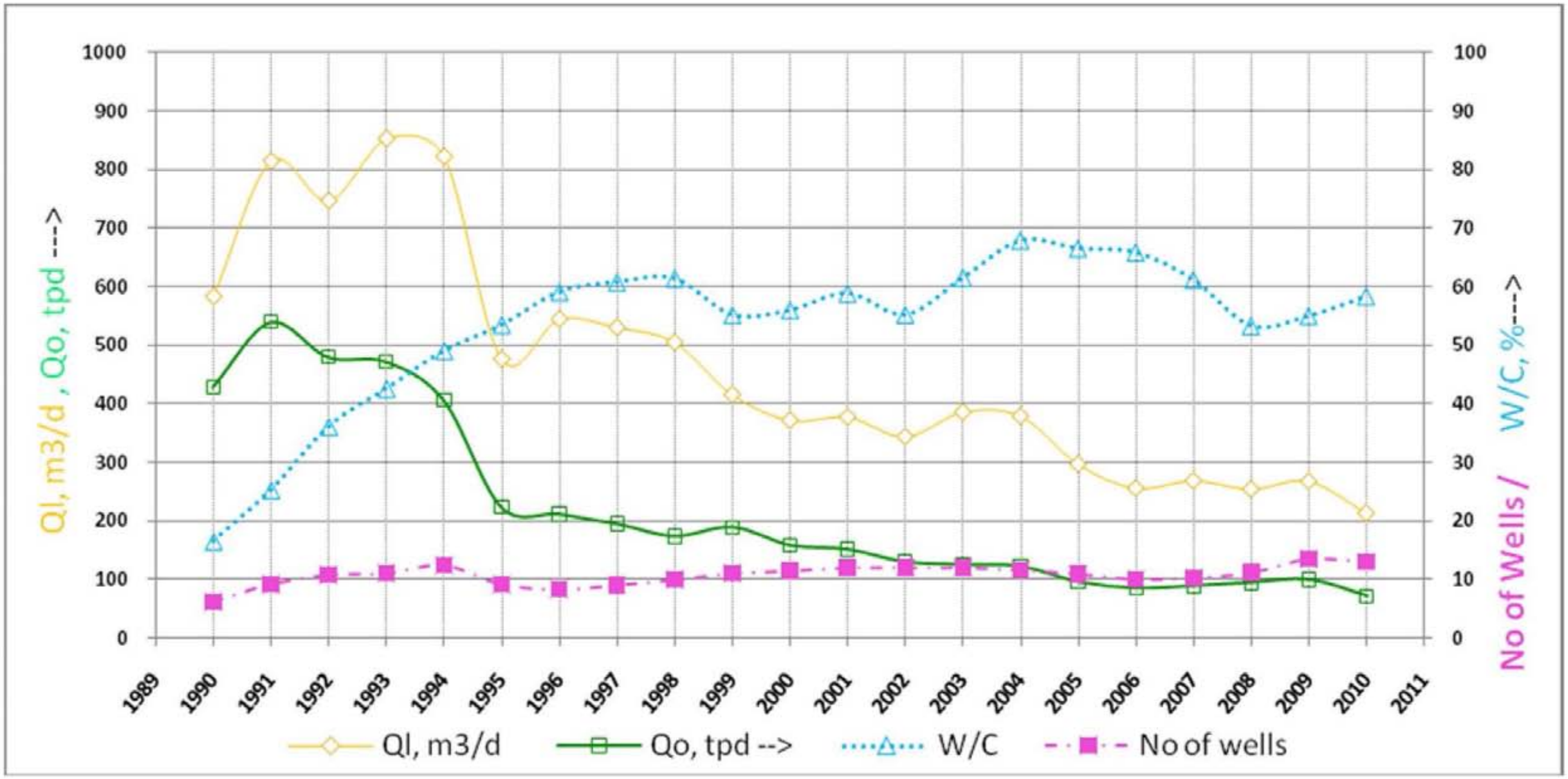

Figure 3. Production performance of Field Block of Kalol-VI Sands of Sobhasan Complex.

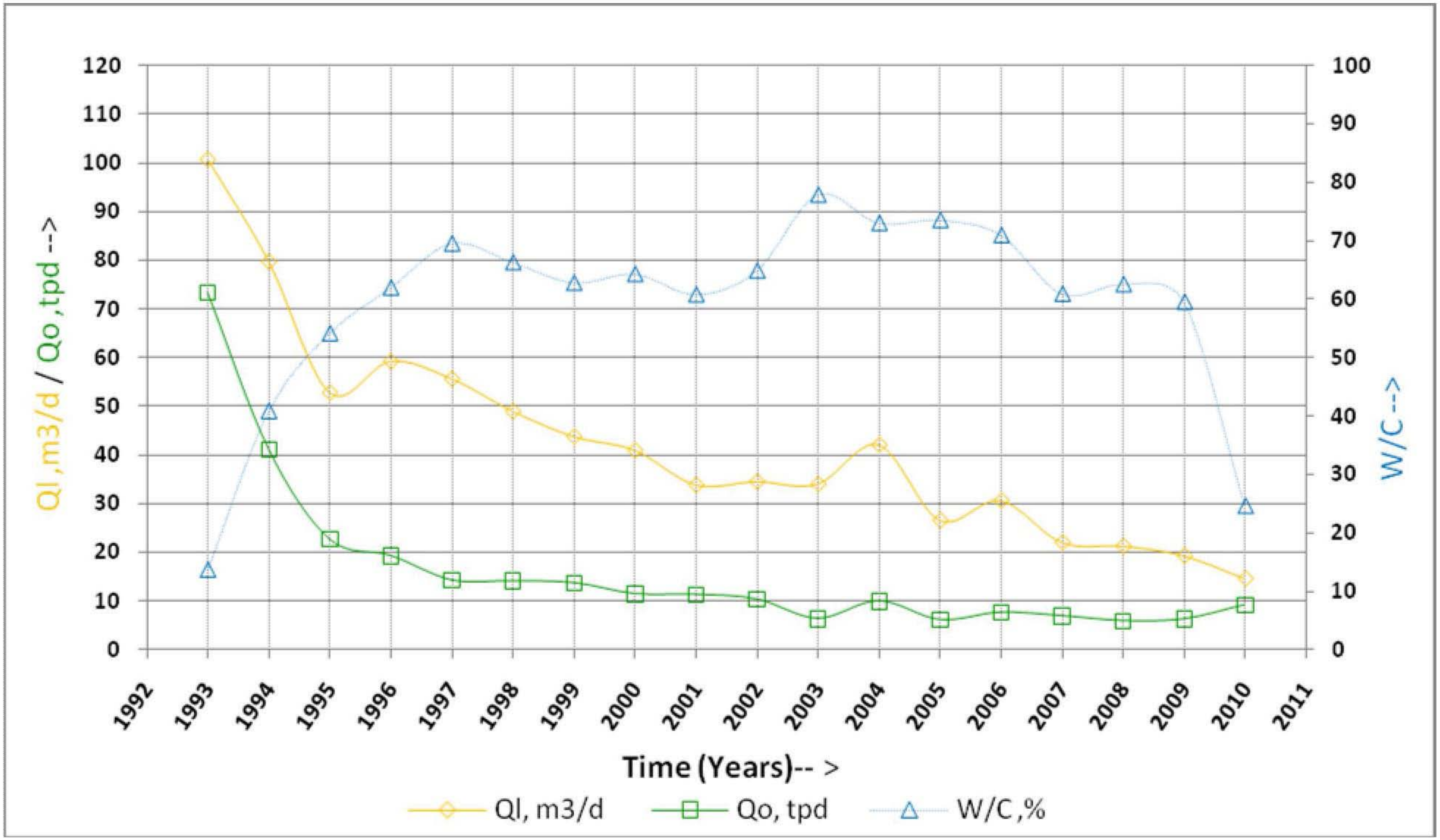

Figure 4. Production performance of Well SB #X of Sobhasan Complex.

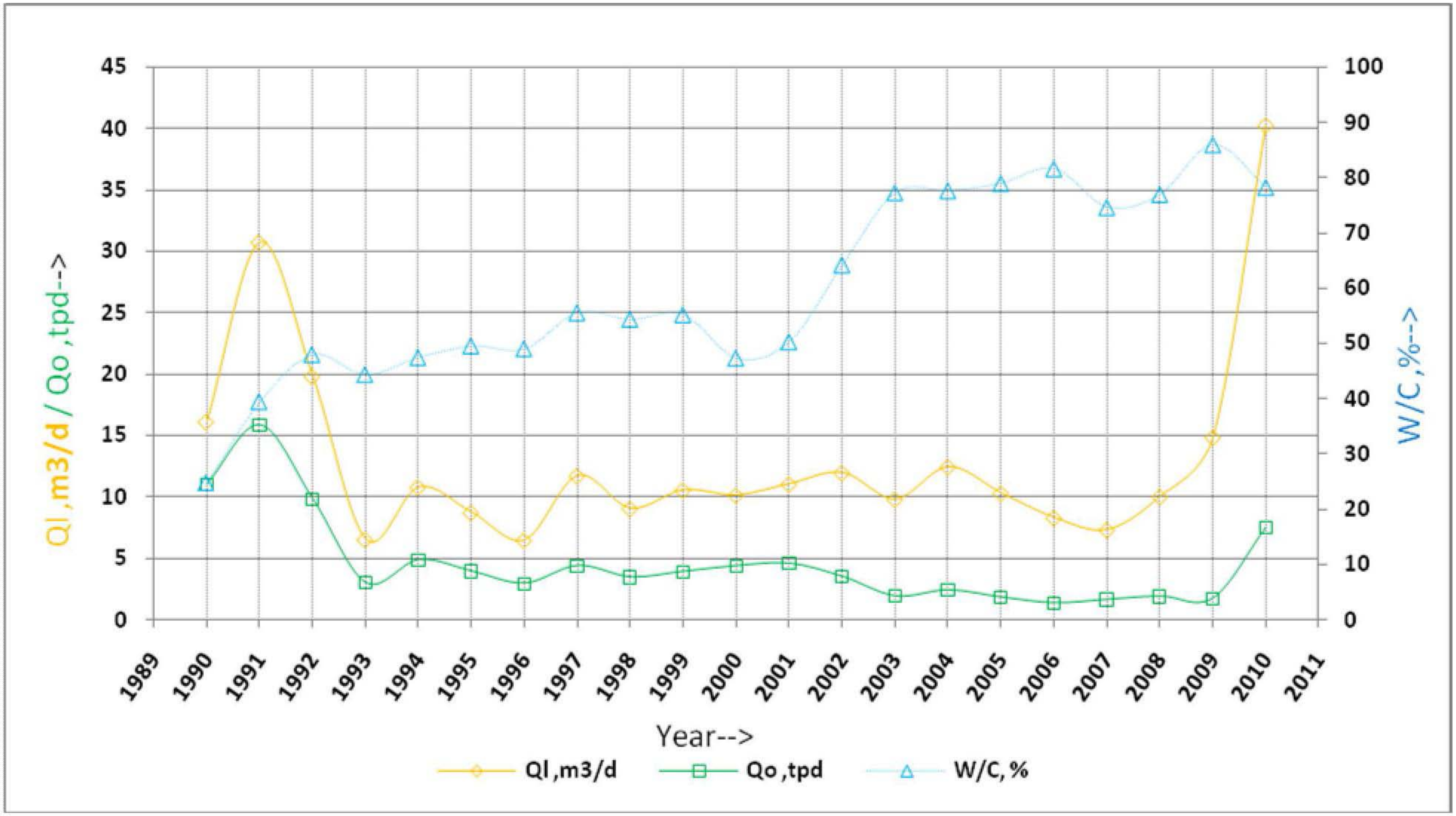

Figure 5. Production performance of Well SB #Y of Sobhasan Complex.

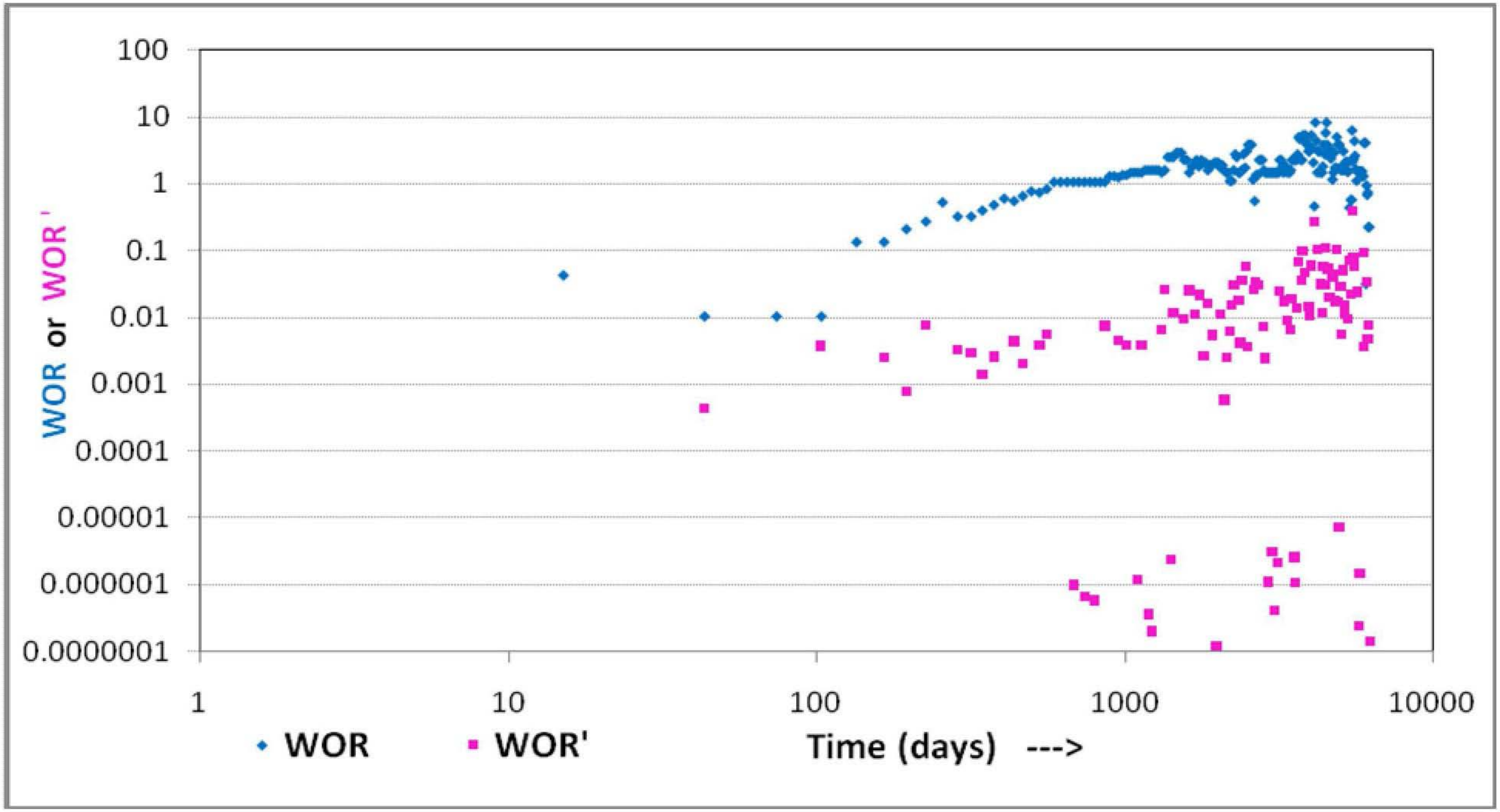

Figure 6. Diagonostic plot of entire production period of SB #X.

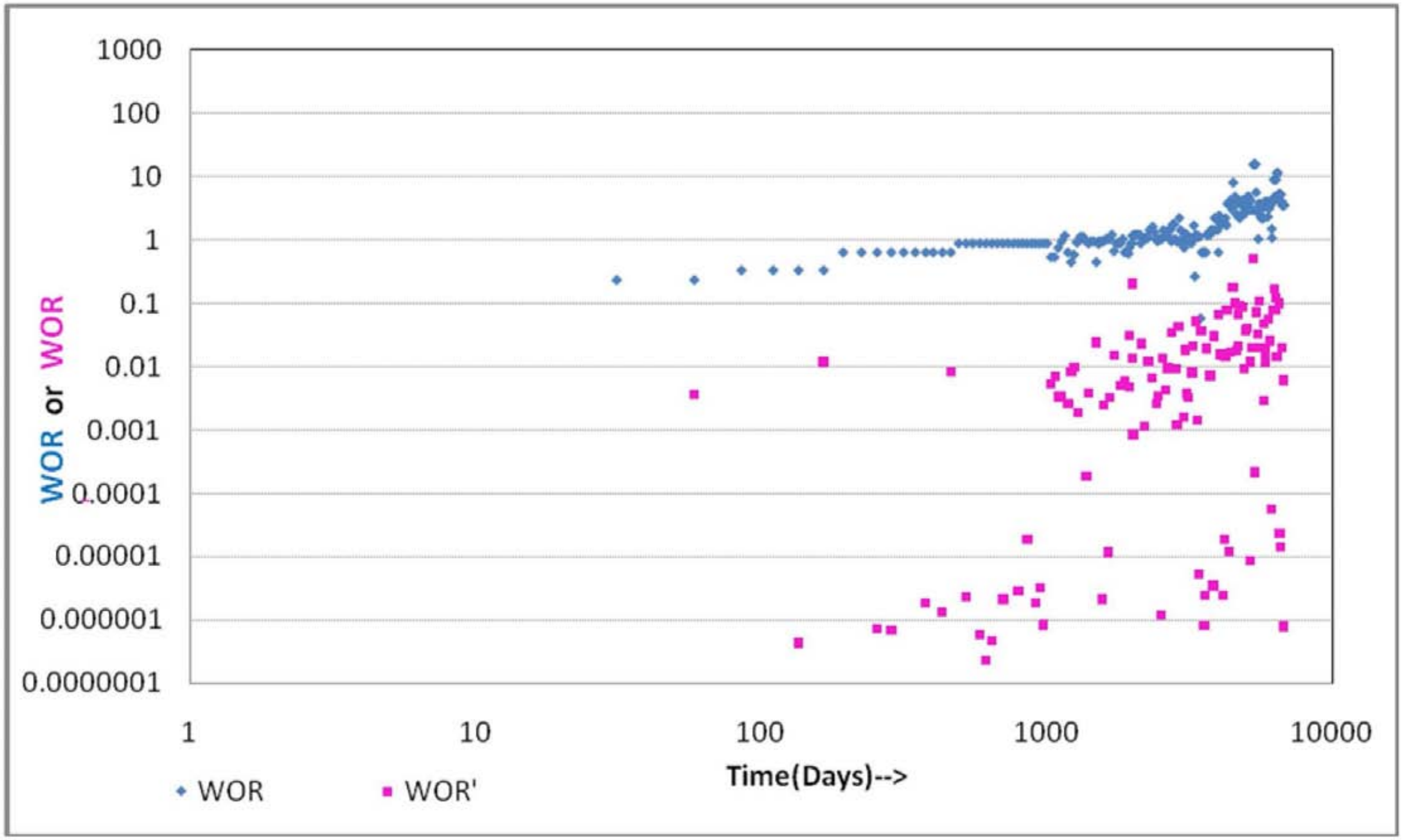

Figure 7. Diagonostic plot of entire production period of SB #Y.

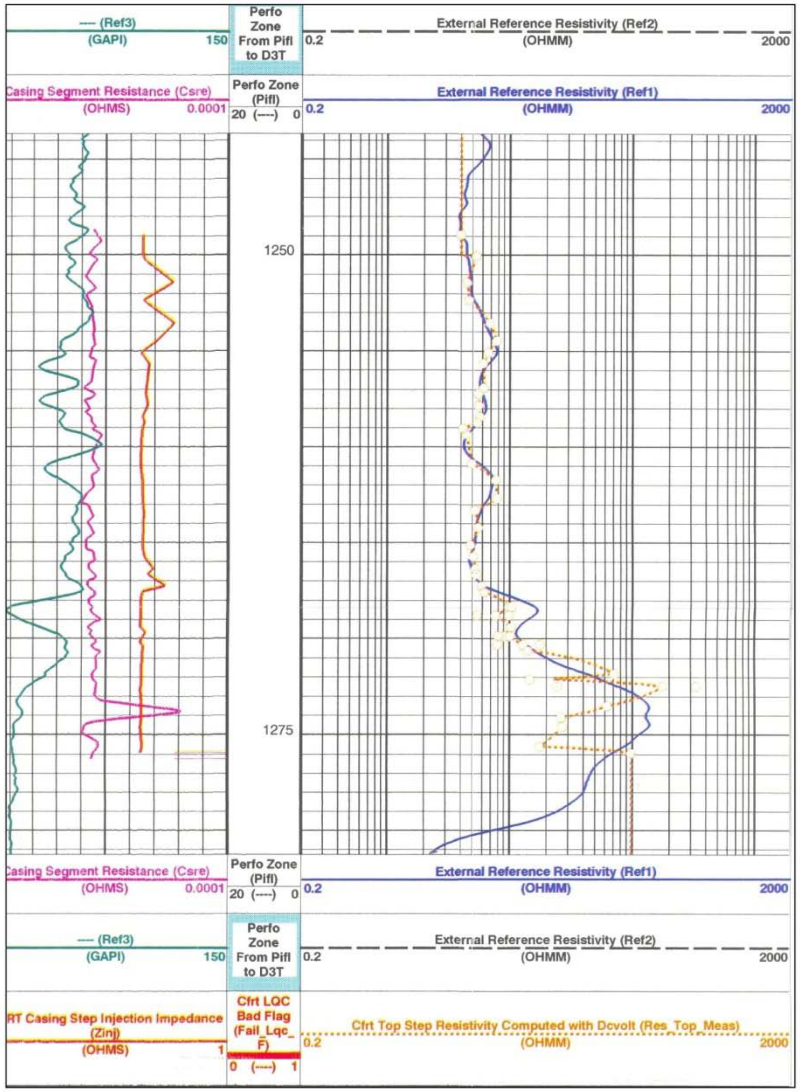

Figure 8. Log motif of Well SB #X.