Identification of Reservoir Facies Within Coal Units Using Well Log Data Integrated With Core And Production Data in Kalol Field, India.

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Summary

The IX and X horizons of Sertha member of Kalol Formation are major oil producers in Ahmedabad Block of Cambay Basin. Apart from production from conventional sand / silt reservoirs, several wells of Kalol field completed exclusively in coal units of IX and X horizons have produced oil. An attempt has been made to analyze the log responses against coal units and integration with core and production data to understand their possible behavior as reservoir. It has been observed that the coal units which appear as monotonous coals from Density, Neutron and GR logs exhibit resistivity variation of 20 to 800 ohm-m. suggesting certain lithological changes. In some wells within these coal units, gradation from coal to carbonaceous shale is evident from GR and Density logs also. Possible reservoir facies within K-IX and X coal units are found to be fractured coals, silt streaks within coal units and fractured carbonaceous shale Very thin laminae of shale / silt present along the bedding planes within coal and carbonaceous shale may be responsible for providing weak planes, congenial for fracturing. The present study has brought out that the SP development, positive separation between micro-resistivity logs coupled with low to moderate resistivity (20-80 ohm-m.) are the log responses which enable to characterize the reservoir facies within coal units.

Introduction

The Kalol field is one of the oldest fields of Cambay Basin, discovered in 1961. The IX and X horizons of Sertha member of Kalol Formation are major oil producers in this field. Silty shaly sandstone layers above, below and between two coal seams, the conventional reservoirs of IX & X horizons are the main producers. Several wells completed exclusively in coal units of these horizons have produced oil especially in southern part of Kalol field. In view of oil production from these coal units, a feasibility study was sponsored by western onshore basin for identification of reservoir facies within coals of K-IX and K-X horizons with the help of well log data. The occurrence of two distinct K-IX and K-X coal units is widespread over the area with varying thickness and they are almost merged together in the northwestern part of the field.

The production of oil from such coal intervals has been debatable so far as their reservoir nature is concerned. In some earlier studies, the possible reservoir facies responsible for oil production from these coal units have been mentioned as fractured coals and thin silty layers within coals. There has also been opinion that fractured coal is not itself a reservoir rather it acts as a conduit to produce from conventional silt reservoirs. However, this possibility does not hold in wells where conventional silts are not prospective and testing exclusively in coal units has produced oil.

In the present study an attempt has been made to analyze the log responses against coal units and integration with core and production data to understand their possible behavior as reservoir.

Methodology

- Megascopic study of coal units in available cores.
- Review of earlier core studies against coal sections.
- Study of log responses against coal units across the field.
- Integration of log, core and production data.
- Selection of log responses helpful for identification of reservoir facies.

The log responses of key wells which have either produced oil from coal units or have conventional cores against coal units, were analyzed critically vis-à-vis core studies and production data. The study was extended to wells in nearby areas to further substantiate the log responses responsible for identification of reservoir facies within coal units. The conventional cores of three wells (results of two

wells A&B presented in Plate-1) were analyzed megascopically and photographed in KDMIPE, Dehradun and one well #C was studied at Regional Geological Laboratory, Vadodra. Apart from these wells the available core/cutting data of 8 other wells was incorporated in the study.

So far, the coal units were broadly considered to be monotonous coal seams as indicated by low density (1.15 – 1.25 gm/cc) , high neutron porosity (60- 80 p.u.), low gamma ray (10-15 API). It has been observed that the resistivity against these coal units varies between 20-800 ohm-m. across the field. SP development has also been observed against these coals in many wells. In some of the wells micro resistivity log also indicates a positive separation between micro normal and micro inverse resistivity indicative of permeable nature of these coals. Gradual reduction of resistivity accompanied by increase of GR and Density and decrease in Neutron porosity within the so called coal units has also been observed in some wells indicating lithological gradation from coal to carbonaceous shale and to shale. The presence of thin laminations of silt within coals has also been observed from logs as well as core data. Core studies also reveal the presence of fractures and permeability paths along the bedding planes apart from vertical/sub-vertical/conchoidal fractures. The integrated analysis of log responses with core and production data for some example wells is given below.

Well #A:

This well is situated in the central part of Kalol field i.e. the main block. The conventional cores (DC#4, 1482-91 m., Rec: 83%) in K-IX and (DC#5, 1511-20 m., Rec: 80.5%) in K-X covered some coal intervals. The core

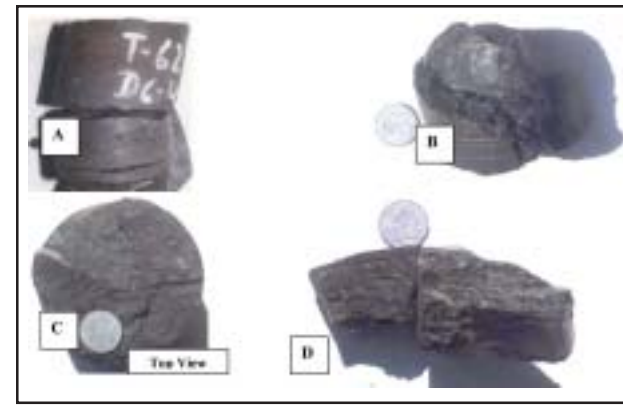

Plate-1. Core Photographs of Well #A, A. Carbonaceous coal showing permeability paths weak planes parallel to bedding planes., **B.** Coal showing conchoidal and sub-vertical fractures., **C.** Coal with vertical and sub-vertical fractures. **D.** Horizontal layering in coal.

DC#4 is described as laminations of coal and carbonaceous shale and DC#5 is Silty shale, carbonaceous shale with silt streaks and lenses and coal in the bottom 3 m. The coal is black in color, soft and brittle having presence of resinous matter at places. Carbonaceous shale is characterized as dark grey, moderately compact and highly carbonaceous having resinous matter at places. The carbonaceous shale shows weak planes parallel to bedding planes as in core photo (Plate-1A). The presence of vertical / sub-vertical fractures and conchoidal fractures are evident on the core photo (Plates- 1B &C). The layered nature of coal and is shown in Plate-1 D. The IX coal shows gradation from coal to carbonaceous shale in the top part (1482-92m) from GR, Neutron and Resistivity logs (Plate-3). The borehole shows cavings in IX coal and top part of X coal, negative SP is developed against both coal units. The resistivity against coals is lower ~ 40 ohm-m. in IX coal and is medium to

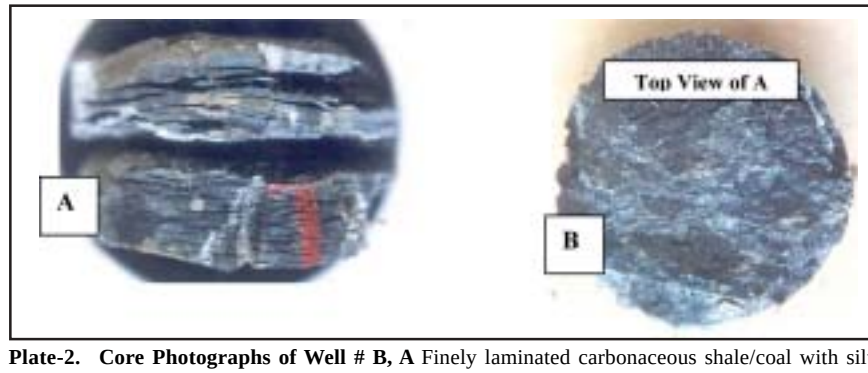

Plate-2. Core Photographs of Well # B, A Finely laminated carbonaceous shale/coal with silt-stone interclations giving rise to splintery nature of the rock which may be responsible for development of reservoir facies. The visible splitting may be caused by dampness during storage at KDMIPE core house.The permeable paths are criss crossing each other. **B.** Top view of core also shows layering structure of coal/carbonaceous coal

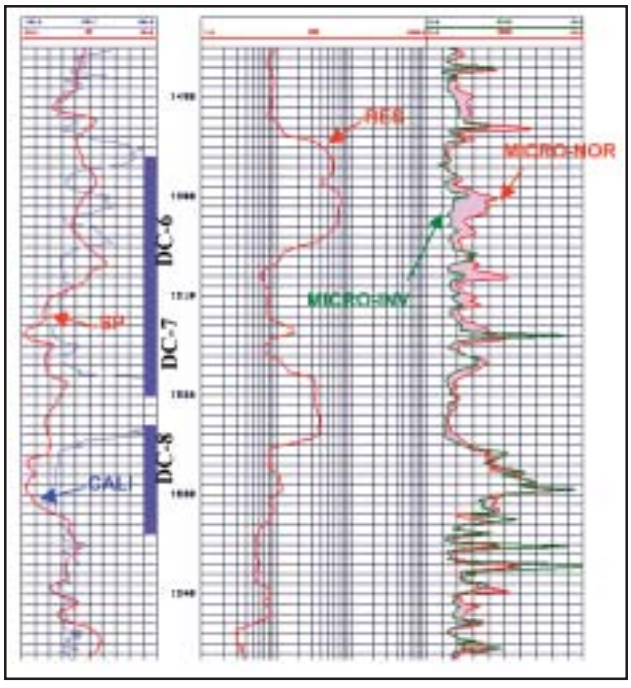

Plate 3. Well # B, X coal highly caved, Lower portion of X is More permeable on SP & Micro resistivity.

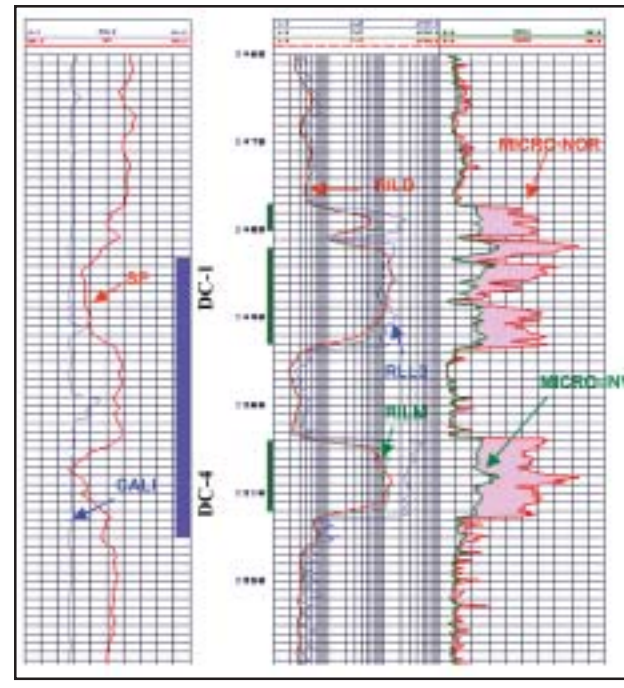

Plate-4 Well # C Good gauged hole, Both coal units are permeable from SP & MEL logs. Resistivity moderate to high.

high ~ 50-100 ohm-m in X coal interval. The perforated intervals 1477.5-1499.5m & 1500.5-21.5m have initially produced oil followed by water.

Well #B:

This well is situated on the western periphery of the main block. The core DC#6 (1496-1511m, Rec.: 59%) and DC#7 (1511-20 m., Rec: 38%), cut in IX horizon. DC#6 is described as coal laminated in nature and the carbonaceous shale finely laminated with silt intercalations giving rise to splintery nature of the rock as shown in core photo (Plate-2). This splintery nature may be responsible for the development of reservoir facies. The permeability paths created by the intercalations parallel to the bedding planes are criss crossing each other to provide vertical permeability also. The visible wide splitting may be due to weathering in humid conditions of storage. The well logs (Plate-4) show IX and X coal units are highly caved from caliper log. The resistivity against IX coal is 40 –70 and in X coal it is 30-40. SP development along with positive separation in MEL logs indicates the permeability character of these coals. However, the MEL log quality is not good due to bad borehole condition. The well was not tested in IX&X horizon.

Well #C :

This well is located I the southern most part of the Kalol field. The coal from DC#1 (1483.5-92.5m, Rec. : 7.2%) representing IX coal unit is described as brittle, fractured and crumbled at places and shows specky fluorescence and moderate solvent cut. Core DC#4 (1509-1515.4 m, Rec.: 48.7%) representing horizon X has brittle coal and carbonaceous shale, underlain by ferruginous claystone / shale. The coal is brittle and light in weight and shows fine silt laminae at places. The fractured coal pieces show specky fluorescence and moderate cut. The log data (Plate-5) shows that borehole is gauged against both IX and X coal intervals and there is good –ve SP development. The MEL logs also show positive separation between micro normal and micro inverse logs which indicates permeability. The resistivity is of medium to high ~50-120 ohm-m and the bottom of IX coal shows gradual fall in resistivity. The testing of X coal alone in the interval 1504-1512m flowed oil on compressor application. Additional perforation in interval 1477-80m and 1482-93m also resulted in flow of oil / gas.

Well #D: (K-IX Coal Int. 1465.5-1480m ; K-X Coal Int. 1492-1496m)

This well is located in the southern part of the main block. K-IX coal is divided by a shale layer at 1470-71m

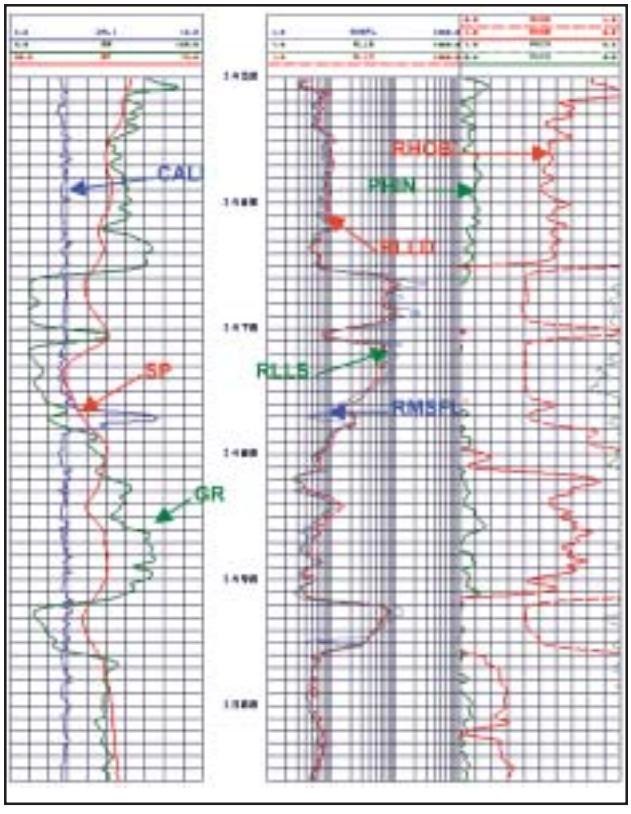

Plate-5 Well # D, Southern part of main block,Gradation from coal to shale via carbonaceous shale from 1474 to 82 m, evident from resistivity, GR and density logs. Good development of SP against laminated carbonaceous shale also. Gradation also observable in X coal.

and X coal is only 4 m thick. A –ve SP is developed against coal intervals (Plate-6). GR, density and resistivity logs show gradation from coal to carbonaceous shale and to shale in the interval 1474-82m in bottom part of IX coal which has even better SP than the top coal interval. Similar gradation is also observed in X coal. The overall resistivity in coal is low to high range ~15-100 ohm m. This well is not tested in IX and X coals.

Well #E: (K-IX & X Coal Int. 1443-1461.5m) :

This well is located on the north western extremity of Kalol field. Both IX and X coal intervals are merged in this well (Plate-7). The resistivity is low to medium ~ 20-45 ohm-m lower in the bottom part and –ve SP is developed indicating development of reservoir characters in coal unit. The well tested in the intervals 1444-49m and 1453-60m. in coal unit produced water @ 18 cu.m/d.

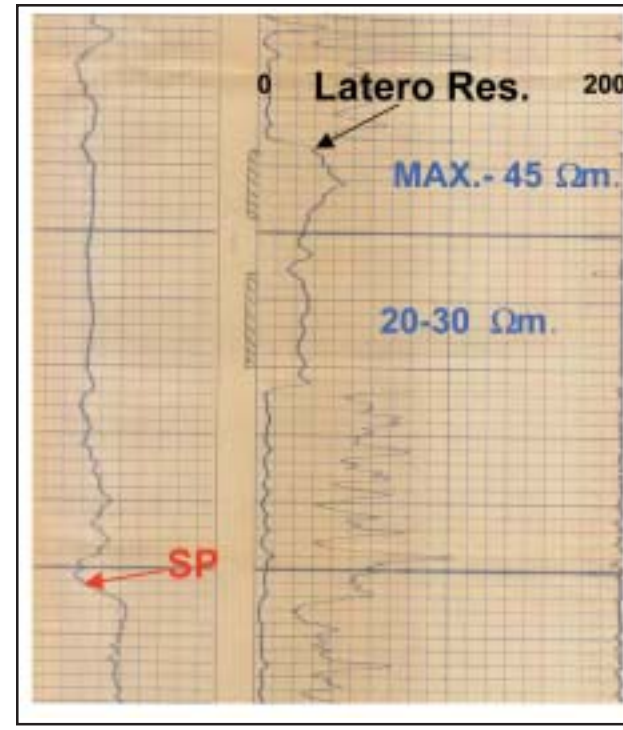

Plate- 6. Well # E, This well in the North western part of Kalol field Produced water @ 18 m3/D The resistivity is low and negative SP is developed in entire unit. The log responses and production data suggests that low resistivity coupled with SP indicates reservoir development.

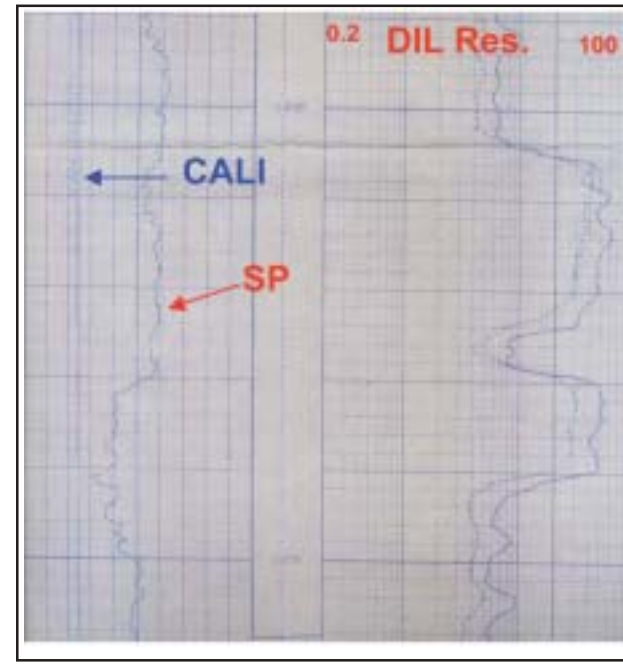

Plate -7. Well # F, Negative SP is developed in the interval 1465-75m.against X coal and underlying silt whereas no SP is see against IX coal. This example Validates the response of SP exhibiting permeability character

Well #F (K-IX Coal Int. 1453-1462.5m; K-X Coal Int. 1464.5-1471m) :

This well is situated south east of Well # E in the northern part of the field. This well represents a good example where SP is developed against the X coal unit whereas no development is seen against IX coal as well as intervening shaly layer (Plate-8). The hole condition is very good and resistivity is varying between 30-40 ohm-m. No testing in coal units have been carried out in this well.

The above descriptions of the K-IX and X coals show that these coal units are not monotonous coals but are comprised of coal, highly carbonaceous shale, intercalated with thin coal / shale/ silt laminae. The core analysis also shows that the fractures in coals and carbonaceous shale and thin silt layers are responsible for reservoir behavior of these coal units. The silt streaks/lenses intercalated within the coals (as reported in core studies) may also be porous and permeable depending upon their thickness, mineral composition and degree of compaction to form reservoir facies. From the above examples it can be concluded that the development of SP against coal units is representative of permeability similar to conventional clastics reservoirs and development of SP, +ve separation between micro resistivity logs and low to medium resistivity (20-80 ohm-m.) are the log features which have been found to represent reservoir facies within the coal units.

Conclusions

1. Wide variation in formation resistivity across the field indicates that the so called coal units of K-IX & X horizons are not only monotonous coals but also laminated with thin intercalations of carbonaceous shale / silt / shale. Gradation from coal to carbonaceous shale and to shale is also visible on conventional logs in some wells.

2. Possible reservoir facies as identified within K-IX and X coal units are Fractured coals, Silt intercalations in form of streaks and lenses within coal units and fractured carbonaceous shale

3. Thin laminations of silt / shale / coal within coals and carbonaceous shales may provide weak planes congenial for generation of fractures.

4. Among conventional logs, the development of SP, positive separation on micro resistivity logs (micro-normal and micro-inverse logs), coupled with low to medium resistivity (~ 20-80 ohm-m.) are indicative of reservoir facies within coal units.

5. Apart from these conventional logs, Dipole Shear Sonic log for permeability and fracture detection and Induced Gamma Ray Spectroscopic logs for elemental analysis to identify silt laminations may prove to be helpful for identification and description of these reservoir facies.

6. The present study may be applied across the Kalol field and adjoining areas for further exploration and development.

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Views expressed in this paper are that of the author (s) only and may not necessarily be of ONGC.

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