2005004

Resistivity Modelling Through Core Log Integration for Low Resistivity Low Contrast K-VA Reservoir of Kalol Field, Western Onshore Basin, India.

Pradeep Kumar, B.S. Bisht, SudheshBabu,

INTEG, GEOPIC, ONGC, Dehradun, INDIA-248195.

Email: pk_randev@yahoo.co.in

Abstract:

Low Resistivity Low Contrast (LRLC) hydrocarbon reservoirs have always been a challenging task for petro-physicists. Identification and realistic evaluation of LRLC reservoirs is of utmost importance not only for production testing decisions but also for effective field development through reservoir modelling and simulation studies. Presence of heavy conducting minerals, grain coating clays in fresh water environment, thinly laminated nature of shaly sands are some of the causatives for low resistivity against hydrocarbon reservoirs. Core log integration is the key for understanding the reasons for low resistivity and formulation of interpretation techniques/induction of appropriate technology.

Presence of heavy conducting minerals, mainly Ilmenite, in significant amount (10-30%) along with some Pyrite and limonitic cement has been inferred from sedimentological studies on core samples of K-VA sand in Kalol Field. It has been observed that against low resistivity hydrocarbon layers, the occurrence of these minerals is discernible from high reading RHOB & PEF logs.The reservoir character against these layers is observed from SP development and separation between shallow and deep resistivity logs.

In the present study, an innovative technique has been developed to compensate for resistivity reduction due to conducting minerals using tool-specific transforms generated fromdata published by logging service companies. After applying the routine bore hole environmental corrections to the log data, multi-mineral model is run using core derived mineralogyand uncorrected resistivity log. Once the mineral volumes are optimised through least square error minimisation technique, a volume-weighted correction for conducting minerals is applied to the deep resistivity log through the generated transform. Finally, the model is re-run with corrected resistivity log to obtain realistic water saturation and porosity estimates.

The technique has been successfully applied in many wells of Kalol field and the computed water saturations were validated with production data and special core analysis (SCAL) results. The study has resulted into identification of new hydrocarbon layers and significant improvement in hydrocarbon saturation (20-50%) leading to reserve accretion and productivity enhancement.The results wereused into Geo-Cellular Modelling and simulation studies of Kalol Field. The use of generated transforms can be extended to LRLC reservoirs of other fields.

Introduction:

Cambay basin in the western part of India is a rift basin bounded on its eastern and western margins by faults trending parallel/sub-parallel to the basin axis. The basin has been divided into five tectonic blocks viz. Sanchor-Patan, Mehsana-Ahmedabad, Cambay-Tarapur, Broach- Jambusar, Narmada-Tapti based upon recognizable basement fault trends and subsurface ridges. Kalol field covering an area of 300 sq. falls in Ahmedabad-Mehsana tectonic block of Cambay Basin and is located 16 Km. north of Ahmedabad city (Fig.-1). The field was discovered in the year 1961 and put on production in 1964. Hydrocarbons are encountered in Olpad, Cambay Shale and Kalol formations of paleogene age. Till date more than 700 wells have been drilled to exploit hydrocarbons from 11 Kalol pay sands viz. K-II to K-XII from top to bottom. This field has OIIP of 150 MMt, out of which only 10 % has been produced so far. K-VA reservoir belongs to Wavel group of Kalol formation of middle to upper Eocene age and is well developed and hydrocarbon bearing in the South Eastern part of Kalol field, marked as study area in Fig.1.The net reservoir thickness of KS-VA varies from 2-15 m. in the study area.

KS-VA sand produces clean oil from reservoir sections having resistivity ranging from 2.5 ohm m. to 80 ohm m in the study area. Presence of heavy conducting minerals, mainly Ilmenite, in significant amount (10-30%) along with some Pyrite and limonitic cement has been inferred from sedimentological studies on core samples of K-VA sand in Kalol Field.

In order to compute realistic water saturations against low resistivity hydrocarbon layers, an innovative technique has been developed to compensate for resistivity reduction due to conducting minerals using tool-specific transforms generated from data published by logging service companies.

The technique has been successfully applied in many wells of Kalol field and the computed water saturations were validated with production data and special core analysis (SCAL) results. The study has resulted into identification of new hydrocarbon layers and significant improvement in hydrocarbon saturation (20-50%) leading to reserve accretion and productivity enhancement. The results were used into Geo-Cellular Modelling and simulation studies of Kalol Field. The use of generated transforms can be extended to LRLC reservoirs of other fields.

Reason for Low Resistivity:

Presence of heavy conducting minerals, grain coating clays in fresh water environment, thinly laminated nature of shaly sands are some of the causatives for low resistivity against hydrocarbon reservoirs. In KS-VA reservoir, the major reason for low resistivity is found to be the presence of mineral ilmenite ($FeTiO_3$) as reported in sedimentological core studies (Fig.-2). Further, weight percentage of ilmenite and other heavy minerals vary from 15% to 25 %. Conventional (triple combo) and high tech (DSI&FMI) log responses of hydrocarbon bearing well-A, are presented in Fig.-3. The KS-VA, reservoir in the interval 1504-1512 m. is very well discernible from SP, Caliper, N-D overlay and separation between shallow and Deep resistivity curves. Presence of Ilmenite through the sand is indicated by PEF curve reading 4-10 units as compared to 1.81 units for quartz and ranging 3-5 units in shales. It is worth noticing that against the interval 1509-10 m having PEF up to 10 units and density 2.6 gm/cc, deep resistivity (M2RX) has decreased to 3 ohm-m and again increased to 5 ohm m. in the interval 1510-13m. The decrease in resistivity can be attributed to the presence of heavy conducting minerals. Moreover, the bottom of the sand is about 34 m above the regional OWC. Compressional, shear and stonley travel times recorded by DSI tool also indicate that the vertical homogeneity of KS-VA sand in terms of porosity and permeability. The textural attributes and distribution of ilmenite grains in the rock indicated in thin section petrography (Fig.-2) is such that it will have minimal effect on porosity. The petrophysical measurements on core samples indicate the porosity ranging from 23-30 %, air permeability 15-110 mD and grain density from 2.62 to 2.98 gm/cc. FMI image data indicates dispersed conducting mineral throughout the layer and more concentrated against low resistivity layer marked on Fig.3. Log responses against water bearing low resistivity layer containing conducting minerals identified from PEF log are presented in Fig.4, where the resistivity has fallen to 0.1 ohm m.

The laboratory study of variation of electrical conductivity with temperature and pressure by Zhang et.al.(Fig.-3) suggests that ilmenite is a conducting mineral at temperature and pressure conditions normally encountered in petroleum reservoirs. The reported conductivity values also indicate that the conductivity of ilmenite is in the almost same range reported for typical pyrites. Further, the conductivity of ilmenite, being of electronic nature, its effect on resistivity log depends upon the operating frequency of tool. Induction type tools such as DIL,HRI, HDIL and AIT, operating at higher frequencies have much more effect as compared to low frequency latero type tools such as DLL, HRLA, MSFL, MLL etc. as detailed by Clavier et.al.(2). Therefore, it becomes very important to apply corrections to apparent resistivity for realistic estimation of water saturation and hence hydrocarbon potential of low resistivity layers.

Resistivity Modelling:

The effect of conducting minerals like pyrite are well known to the petrophysicists but application of appropriate corrections to apparent resistivity for such minerals needs a fresh impetus for realistic evaluation of LRLC reservoirs. Modelling of resistivity tool response depending upon textural attributes of pyrite dispersed in quartz sand for HDIL tool with operating frequency of 10-150 KHz has been published by Baker Atlas(1). The transform for correction of recorded apparent deep resistivity has been developed based upon data published by Baker Atlas for galvanic effects and presented in Fig.-6. The inductive effect has not been incorporated due to its insignificant contributions at the operating frequency range of the HDIL tool. Because of the fact that HDIL tool has been used extensively in the last few years in the fields of Cambay basin, where the problem of low resistivity due to conducting heavy minerals is prevalent, the present innovative technique to implement modelling results through integration with multi-mineral ELAN processing has a special significance towards LRLC reservoirs. Another very important and pertinent study on the effect of pyrite on log responses based upon laboratory measurements on pyrite chunks, field cores and synthetic cores was carried out by Clavier et. al.(2) to provide correction factors for resistivity logs recorded by various tools operating at different frequencies(Fig.-7). The salinity of saturating brine used for laboratory measurements on core samples matched well with the formation water resistivity in the study area. This study has also been incorporated to model resistivity log data recorded with DIL tools in the study area.

Methodology and Workflow:

In order to compute realistic water saturation in this LRLC reservoir, the following workflow has been designed.

- Selection of mineral model based upon mineralogy reported in core studies (XRD,SEM, thin section petrography & EDEX etc.), log responses and cross plots of log data.

- Determination of processing parameters of selected minerals.

- Multi-mineral processing of log data with selected model to compute and optimise volume of conducting heavy mineral, ilmenite as V_{MIN} has been estimated to be used in the transform for resistivity log correction.

- Correction of deep resistivity(M2RX&DIL) weighted by computed volume of conducting heavy mineral, V_{MIN} through transform for HDIL tool,

  $$\mathbf{M2RXC= M2RX* (71.084* V_{MIN}^{3} -32.4 * V_{MIN}^{2} + 6.5449*V_{MIN} + 0.872)}$$

  and for DIL tool, **RILDC= RILD+ 0.125*V_{MIN}** has been applied.

- Re-processing of data using corrected resistivity (M2RXC or RILDC) as resistivity as input channel in ELAN plus or any other multi-mineral model for effective water saturation, porosity and clay volume.

Discussion of Results:

ELAN processed results using recorded apparent resistivity M2RX along with log data for well-A are presented in Fig.-8. Low resistivity nature of the KS-VA reservoir has already been discussed above. Against the interval 1504-15012 m., the estimated volume of ilmenite varies from 5-27 %, porosity from 22-33% and water saturation from 45-70%. The petrophysical measurements on core samples indicate the porosity ranging from 23-30 % and permeability 15-110 mD. The final ELAN processing was carried out using the corrected deep resistivity and selected mineral model. The comparative results of ELAN processing of KS-VA sand in Well -A using raw and corrected resistivities are presented in Fig.-9.The resistivity of the whole sand unit increased about 10-50% depending upon the ELAN computed volume of heavy mineral, ilmenite and water saturation decreased by 15-20%. In the earlier studies the low resistivity interval is either interpreted as shale or water sand.The well K-674 presently perforated in the high resistivity interval 1503-1509 m has produced 11065 m3 of oil and 3.51 Mm3 gas during Sept, 2011 to Oct., 2013 with almost nil water cut. The well is presently under work over job due to tubing leakage.

In well-B, processed data with apparent and corrected resistivity, covering two reservoir layers in the intervals 1431-1436.5 m and 1440-1446 m are presented in Fig.10. The corrected resistivity represented by green curve and improved water saturation curves filled with magenta colour indicates substantial improvements. Both the intervals produced commercial quantities of hydrocarbon @ 20m3/d and 25 m3/D respectively.

Both the field examples establish the efficacy of the technique and robustness of the work flow for realistic evaluation of LRLC reservoirs.

Conclusions:

Core log integration is the key to successful modelling of resistivity log data for improved petrophysical evaluation. Heavy minerals are widespread in significant quantities in fine grained/silty Kalol sands and need to be incorporated in petrophysical evaluation work flow. The conducting minerals decrease resistivity appreciably to the level of rendering hydrocarbon reservoirs LRLC. Corrected deep resistivity gives realistic water saturation in studied wells and will results into enhanced productivity, reserve accretion and better field development. High tech logs such as Elemental Capture Spectroscopy, Nuclear Magnetic Resonance, Tensor resistivity, Borehole imaging and multi-pole Sonic along with conventional cores in few future wells will help for better understanding and reservoir characterisation. The use of generated transforms and petro-physical workflow can be extended to LRLC reservoirs of other fields.

Acknowledgements

The authors are indebted to Shri Anil Sood, GGM-HOI-GEOPIC, Dehradun, India for providing the technical input and guidance for writing this paper. Thanks are due to Shri AK Tandon Head-INTEG, GEOPIC, Dehradun, India for providing all kind of support for this work. The authors are grateful to the concern geoscientist of this domain for providing necessary input during the project work and writing this paper. We thank ONGC management for allowing us to submit this paper in Geo-India 2015, 3rd South Asian Geosciences conference and exhibition.

The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.

References:

1. Tabarovsky L., Georgi D., 2000, “Effect of Pyrites on HDIL Measurements”, SPWLA, 41st Annual Logging Symposium, June 4-7,2000.
2. Clavier C., Heim A., Scala C., 1976, “Effect of Pyrite on Resisistivity and Other Logging Measurements”, SPWLA 7th Annual Logging Symposium, June 9-12,1976.
3. Jena A.K. et. al, 2012, “Integrated Study of K-VA pay sand of Kalol Field, Cambay Basin,.
4. Gupta G.D., Banerjee Nirupama, 2012, “Sedimentological Studies of Core Plug Samples from Wells of Kalol Field, Western Onshore Basin”, Unpublished ONGC Report, KDMIPE, Dehradun.
5. Hazarika P.K., Singh R.P., Sharma D.N., 2004, “Mineralogy, Microfacies and Reservoir Petrography of KS-IV & V paysands of Kalol Field” , unpublished ONGC report, IRS, Ahmedabad.
6. Zhang B.H. et. al, 2005, “Electrical conductivity Measurement of FeTiO3 Ilmenite at High Pressures and Temperatutres.”, Miasa International Intern Program 2005, supported by Ministry of Education, Culture,Sports, Science and Technology of Japan.

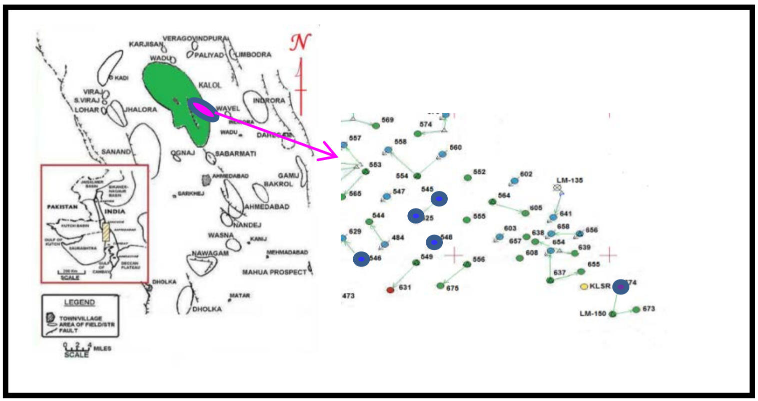

Fig-1., Study Area, SE part of Kalol field, Cambay Basin

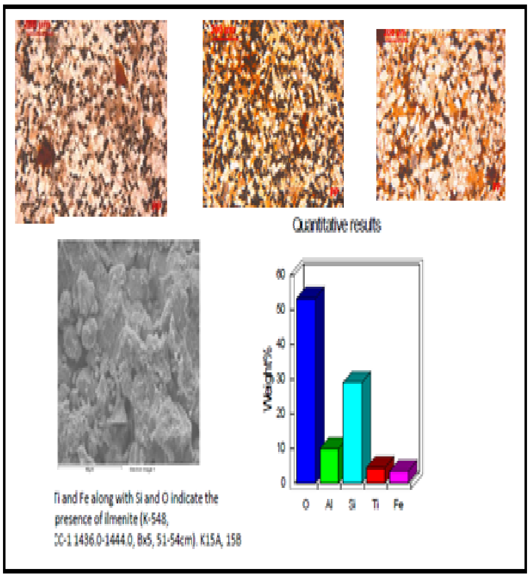

Fig.-2, Core Studies indicating presence of ilmenite (dark coloured grains) in significant amount. (Courtesy Gupta. G.D. et. al.)

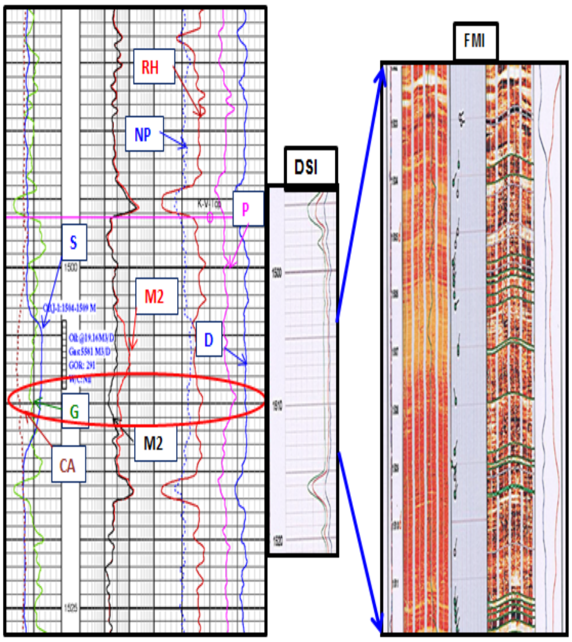

Fig.-3 : Well-A, Convention and High-tech Log Responses against low

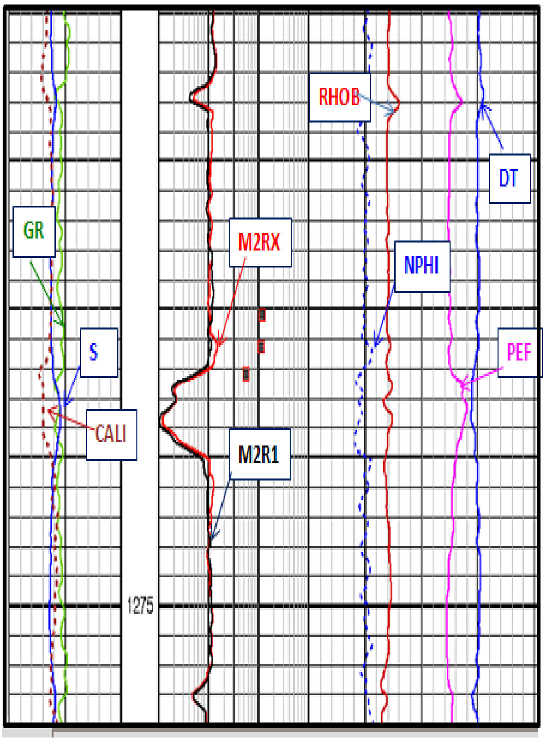

Fig.-4: Log responses against water bearing low resistivity layer

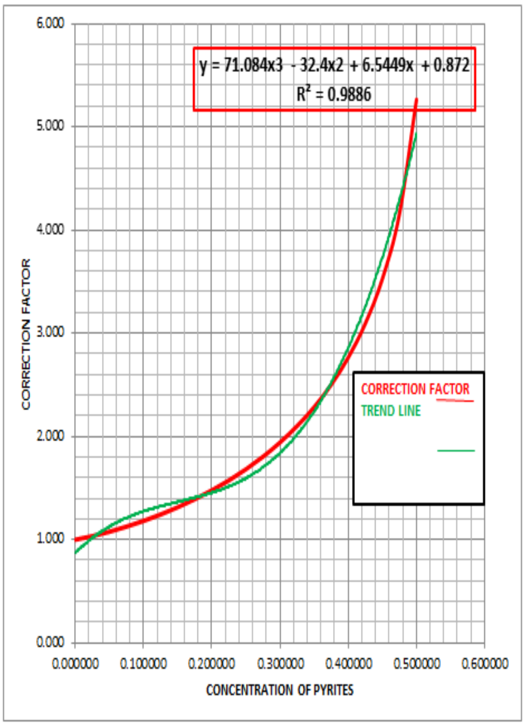

Fig. 6 Regression of modeled resistivity correction factor for HDIL tool as a function of pyrite concentration (Courtesy : Clavier et. al., 1976)

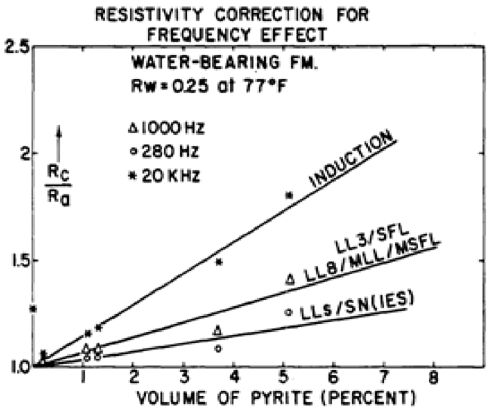

Fig.7: Laboratory measured resistivity correction factor for various induction and latero type tools as a function of pyrite concentration (Courtsey : Clavier et. al., 1976)

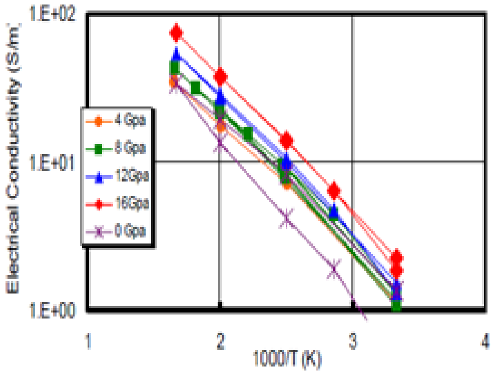

Fig.-5. Ahrenius plot of Electrical Conductivity of FeTiO3 Ilmente (courtesy Zhang et al.)

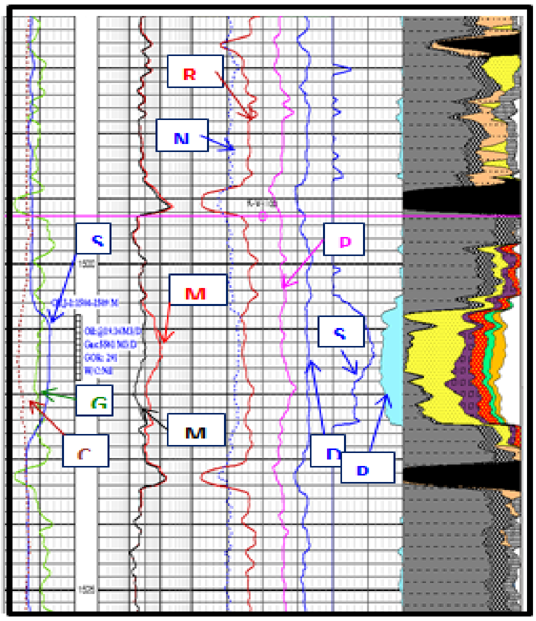

Fig.-8 : ELAN processed results for mineral volumes , porosity & water saturation along with conventional logs

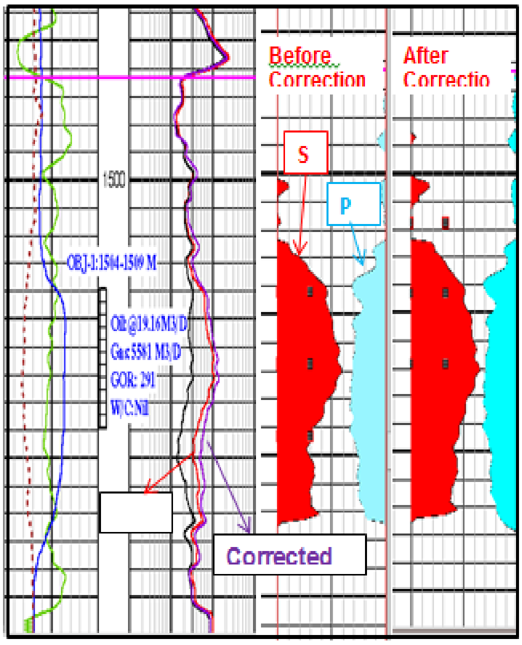

Fig.9.: Computed water saturation before and after resistivity correction

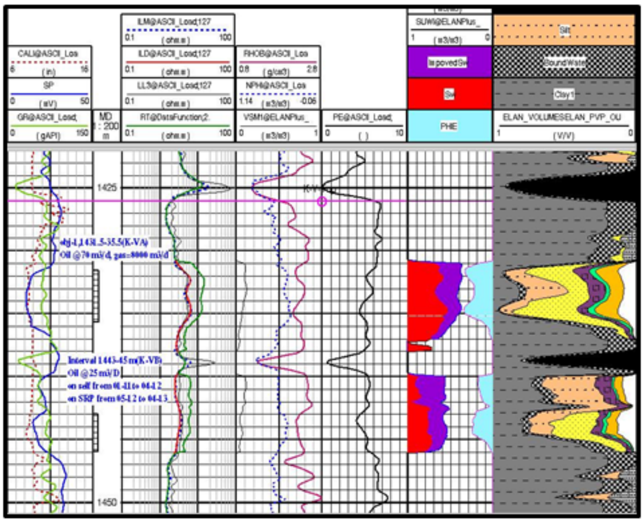

Fig.-10, Well-B : Comparative ELAN results and resistivity