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Analysing the Causes of Low Resistivity in Hazad Sands through Rock Characterization -An Integrated Case Study of GS-12 Sand of Gandhar Area of Cambay Basin

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Abstract

Hydrocarbon bearing GS-12 sands in some parts of Gandhar area of Cambay Basin are low in resistivity. The exact reasons behind this are not well understood. In the absence of this proper reservoir characterization and evaluation for hydrocarbons becomes difficult with the result that some low resistivity hydrocarbon reservoirs might be missed or poorly evaluated.

The study area is in the central part of Gandhar field. The objective of this study was to analyse the causes behind low resistivity through rock characterization by detailed integrated analysis of logs and core data. Core samples of GS-12 sand were studied for clay and minerals volume and grain size. The results were then integrated with log analysis. Concept of petrofacies has been used to understand the reasons behind low resistivity.

Three types of petrofacies have been identified in the low resistivity reservoirs of GS-12 sand unit. These are: P1 (micro-porous clay rich), P2 (Quartz rich) and P3 (Pyrite rich). The analysis shows that the main clay minerals are Kaolinite and Chlorite. Pyrite is found to be present in high concentration. Core and CMR log analysis shows that the grain size of GS-12 sand is small, equivalent to the size of silt.

The study shows that the causes which have a role to play in lowering the resistivity of GS-12 sand are: clay type and their mode of distribution, grain size, presence of conductive mineral-Pyrite, and salinity of formation. The study establishes that no single effect can be attributed to the cause of low resistivity in GS-12 unit of Gandhar area. Low resistivity, in fact, is a combination of two or more of the above mentioned effects. However, the type of facies seems to be the deciding factor as to which of these effects will play a dominant role in lowering the resistivity of GS-12 reservoir sands. The study has concluded that if the facies is P1, then the dominant effect which causes low resistivity will be of clay type and their mode of distribution. If the facies is P2, then the dominant effect which causes low resistivity will be of grain size. If the facies is P3, then the dominant effect which causes low resistivity will be of presence of conductive mineral-Pyrite.

The integrated study of GS-12 sand has helped to demystify the low resistivity phenomenon leading to a better understanding of the reservoir behaviour and has allowed the interpreters to formulate a reliable mineralogical model for water saturation estimates.

Introduction

The Gandhar Field is situated in the Broach Depression in the southern part of the Cambay Basin, western India. The hydrocarbons in the field are trapped primarily by updip pinch-out of Middle-Upper Eocene Ankleshwar Formation fluvio deltaic sandstones. The hydrocarbons occur in the Hazad Member, which contains 12-13 sandstone units (GS-0 at the base to GS-12 at the top) separated by intra formational shales. In some areas, few sandstone units, notably Hydrocarbon bearing GS-12 sands are low in resistivity. The exact reasons behind this are not well understood. In the absence of this proper reservoir characterization and evaluation for hydrocarbons becomes difficult with the result that some low resistivity hydrocarbon reservoirs might be missed or poorly evaluated. The objective of this study was to analyse the causes behind low resistivity of such hydrocarbon bearing sands, through rock characterization by detailed integrated analysis of logs and core data.

Methodology

In order to achieve the aforesaid objectives a sequence wise methodology has been adopted. For the sedimentological analysis, mineralogical assemblage and petrophysical parameters of GS-12 sand of the area, detailed sedimentological and petrophysical studies have been carried in the respective labs on the available core samples in the study area. Integrating these two studies with detail log analysis, an attempt has been made to understand the reasons behind the low resistivity of GS-12 sand unit. Wells have been selected on the basis of core and log data availability and representing a particular part of the study area. These wells have been studied in detail to understand the reasons behind low resistivity of GS-12 sands.

Discussion and results

Log and core analysis of the **GS**-12 pay sands reveal that GS-12 pay sands forming the reservoir rocks in Gandhar field are made up of massive, argillaceous and fine to coarse grained and sandstone. These sandstones are dominated by texturally immature quartz wacke. The main diagenetic minerals are pore filing Kaolinite, grain-coating Chlorite clays, Quartz overgrowths and widespread disseminated Pyrite. Anomalous high presence of Pyrite is observed in cores (Plate:D). Clay mineral association is mainly represented by the dominant presence of Kaolinite and Chlorite in lesser amount (Plate: B, D). Chlorite is usually iron rich, at most places. Bulk mineral analysis of many samples shows the presence of Pyrite in appreciable amounts. The anomalous high presence of Pyrite is also confirmed by energy dispersive X-ray spectrometer analysis. Grain size studies through logs and cores reveal the presence of small size of grains in the reservoir of these low resistivity GS-12 sands which is also evident in the reservoirs with little to no clay.

Different types of facies are encountered in low resistivity GS-12 sands of Hazad Formation of Gandhar area. These have played an important role behind the cause of low resistivity. Therefore, GS-12 sand units have been classified and segregated into facies type through integration of log motifs and core information corresponding to predominant lithology/ facies in reservoir section. The concept of petrofacies has been used to classify the GS-12 sand into units on the basis of log character- dominant pore geometry and degree of variation in mineralogy. This has led to pinpoint the dominant cause of low resistivity associated with a particular type of petrofacies.

After analysing the logs and cores of low resistivity GS-12 units, it is inferred that these low resistivity units can be categorized into three petrofacies types. These three petrofacies are named for the dominant pore geometry and degree of variation in mineralogy: (1) P1-Microporous Clay rich, (2) P2-Quartz rich and (3) P3-Pyrite rich (Plate: A). All these three petrofacies have reservoir potential. After detail and exhaustive study of logs and core data, it is inferred that the effects which have a role to play in lowering the resistivity of GS-12 sand of Gandhar are: Clay type and their mode of distribution, Grain and pore size, Presence of heavy conductive mineral-Pyrite and salinity of formation water. These are discussed below.

A. <u>Clay type and their mode of distribution</u>

Clays are the primary cause of lowering the resistivity of pay sands and can form during and after deposition. Their mode of distribution can enhance the effect of low resistivity, especially if they are distributed in the formation as dispersed clays[1]. The Present study on cores of GS-12 sand has shown that reservoir sands of GS-12 unit of Hazad formation are made up of mostly fine to texturally immature Quartz wacke with abundant clay matrix. Detail log and core analysis through Thorium-Potassium NGS X-Plots, neutron- density X-plots and SEM-XRD studies (Plate: D), have confirmed the identification of clay minerals and have shown that Kaolinite and Chlorite are the main clay minerals in GS-12 unit of Gandhar sands. Kaolinite, however, is found to be the dominant clay. The size differences between dispersed clay grains and framework grains allows the displaced clay grains to line or fill the pore throat between framework grains. These effects cause dramatic lowering of resistivity values. SEM studies carried out on GS-12 cores of wells in the present study have shown that Kaolinite is found to be dispersed and present as pore fill clay while Chlorite is dispersed and seen to be present as coating on grains (Plates:B). This creates micro-pores. This also greatly increases the surface area and formation of capillaries. Presence of micropores and high irreducible water is also confirmed by CMR log analysis (Plate:E). Increase in surface area causes low resistivity as due to their small size, clays present a large surface area on which water adheres. Further the SEM studies reveal that Chlorite presents as grain coating is heavily Fe rich. This further reduces the resistivity. All these effects due to clay type and their distribution have led to lowering of resistivity of reservoir sands of GS-12 unit of Hazad formation. The present study has indicated that this effect of clay type and their mode of distribution in lowering the resistivity of GS-12 sands of Gandhar field is dominant in P1 (micro-pores clay rich) type of petrofacies (Plate: B).

B Grain and pore size

Small grain size can lower resistivity values over an interval despite uniform mineralogy and little or no clay content. This smaller grain size has more micro pores and capillaries which hold more irreducible water which leads lowering of resistivity of the reservoir depending upon the water salinity. In order to get an idea about the grain size and its effect in lowering the resistivity, grain size study of low resistivity GS-12 reservoir sands of Gandhar area was carried out through the analysis of the available CMR log data and through analysis of cores of Gandhar wells. CMR log analysis was carried out for GS-12 unit. The T2 log distribution curve indicates that most of the signal comes from micro pores and capillary bound fluid (3ms- 33ms) which corresponds to irreducible water and less signal is from free fluid (greater than 33ms). This shows the dominance of fine grains in low resistivity GS-12 sands leading to formation of capillaries which hold more irreducible water thus lowering the resistivity. These micro pores and capillaries are seen to be present even in little or clay-free low resistivity GS-12 units of Gandhar area. From the CMR logs of these wells, pore size and grain size plots were also generated. These plots have shown that grain size in these wells varies between 17-38 microns (Plates: E). These facts establishes that the grain size is small and corresponds to silt. The core results also validate the log results. The study of CMR log analysis and core studies establishes the dominant presence of small and fine nature of grains in the low resistivity GS-12 unit of Gandhar area. This is true even for little or clay free low resistivity GS-12 reservoirs. This Effect of grain and pore size in lowering the resistivity of GS-12 sands of Gandhar field though found to be prevalent in all the three petrofacies type of GS-12 sands but becomes dominant in P2 (Quartz rich) type of facies (Plate: C), due to absence of other effects.

C Presence of heavy conductive mineral-Pyrite

A heavy conductive mineral like Pyrite if present in reservoirs can lower the resistivity drastically. However, the electrical property of sands with Pyrite is dependent on the amount and distribution of Pyrite and the frequency of the measuring current[2]. Clavier in his paper[2] has shown the effects of Pyrite on resistivity, density, neutron, sonic and PEF. He has shown the resistivity readings will be badly in error in the reservoir sections where the pyrite concentration is large enough to ensure electrical continuity. However, the crystal clusters of pyrite may easily form continuous network even at low Pyrite concentration. Therefore, when electrical continuity exists through the Pyrite phase, even at low concentration, the measured resistivity decreases dramatically at any frequency and cannot be used for saturation determination. From the SEM and XRD studies on the cores of GS-12 unit it is found that Pyrite appears in the form of small clusters of crystals unevenly distributed throughout the intergranular porosity of the reservoir rock which can form a continuous network of electrical continuity. Abnormally high concentration of pyrite is noticed in some cores of the GS-12 unit in wells where core study was carried out (Plate: D). It has been found that in most wells, Pyrite generally appears in association with high amount of clays. However, in some wells, drastic lowering of resistivity is observed in GS-12 unit. In these wells the lower part of GS-12 is clean and has high resistivity but the upper part shows drastic reduction in resistivity. This upper part does not appear to be highly shaly so as to cause this sharp drop in resistivity. Density-Neutron X-plot of these wells shows a trend towards high density-low porosity area indicating the presence of a high density mineral. On analyzing the log motif of this upper part it is observed that PEF, density and neutron values are relatively high as compared to the lower part. Also the X-Plot of RHOB vs. PEF shows increase in PEF values with increase in RHOB values. These are the indicators of Pyrite presence in high concentration. This shows that Pyrite does play an important part in lowering the resistivity of GS-12 unit in such wells. Such type of facies is classified as P-3 petrofacies. The present study shows that this effect is more pronounced and dominant cause in lowering of resistivity of GS-12 unit in wells with P3 (Pyrite rich) type facies (Plate: D).

D. Salinity of formation water

Salinity of formation water affects the resistivity of reservoir sands. High formation water salinity will lower the resistivity of the sands as high salinity formation water will make the water conductive thus lowering the resistivity of the reservoir sands. This effect is more where the reservoirs are silty/clayey as more bound water is associated with clays/silt and capillaries (micro porosity). Clay minerals have a substantial negative charge which attracts cations such as Na^+ and K^+ when the clay is dry. When the clay is immersed in water, cations are released, increasing the water conductivity thus lowering the reservoir resistivity. All available water salinity data of GS-12 sand unit of Hazad formation in Gandhar was analysed. It is observed that in the Eastern to North eastern part of Gandhar field salinity of GS-12 sand is generally high from 20 gpl to 34 gpl while in the western part of Gandhar field where the resistivity of GS-12 sand unit is general high; the formation water salinity of GS-12 sand is generally low from 10 gpl to 12 gpl. As most of the low resistivity GS-12 sand wells are located in the Eastern to North Eastern part of the Gandhar field, it follows that water salinity has a role to play in lowering the resistivity of GS-12 sand unit of Hazad Formation of Gandhar field.

Conclusions

After detail and exhaustive analysis of logs and core data, it is inferred that the effects which have a role to play in lowering the resistivity of GS-12 sand of Gandhar are: Clay type and their mode of distribution, Grain and pore size, Presence of heavy conductive mineral-Pyrite and salinity of formation water. No single effect can be attributed to the cause of low resistivity in GS-12 unit of Gandhar area. Low resistivity in GS-12 unit of Gandhar area, in fact, is a combination of two or more of the above effects. However, the type of facies seems to be the deciding factor as to which of the effects will play a dominant role in lowering the resistivity of GS-12 reservoir sands. If the petrofacies is of P1 (micro-porous clay rich) type, then the dominant effect which causes low resistivity will be due to clay type and their mode of distribution. This result in high surface area, high micro porosity due to clay and high irreducible water saturation which ultimately become the cause of low resistivity. If the facies is of P2 (Quartz rich) type, then the dominant effect which causes low resistivity will be due to smaller grain size. Grain size of even little or clay free GS-12 reservoirs is small and is comparable to silt. Smaller grain size will have large surface area, more irreducible water which ultimately becomes the cause of low resistivity. Formation water salinity effect will also be their due to high irreducible water associated with smaller grain size. If the facies is of P3 (Pyrite rich) type, then the dominant effect which causes low resistivity will be due to presence of heavy conductive mineral-Pyrite. Pyrite forms the metallic electrical continuity path thus lowering the resistivity drastically. The present study is able to explain the reasons behind low resistivity of GS-12 sand unit. Further on the basis of the identified petrofacies: P1, P2 and P3 of low resistivity GS-12 sand unit, it is also able to pinpoint the dominant cause of low resistivity associated with a particular type of petrofacies of the GS-12 sand unit.

Plates

Plate: A

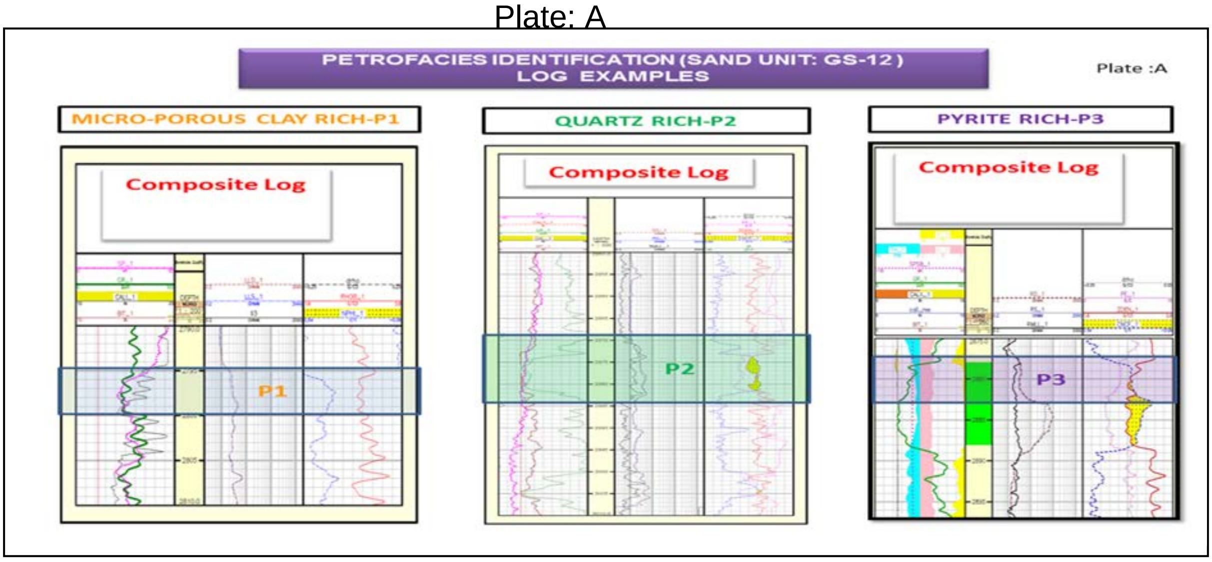


Plate: B

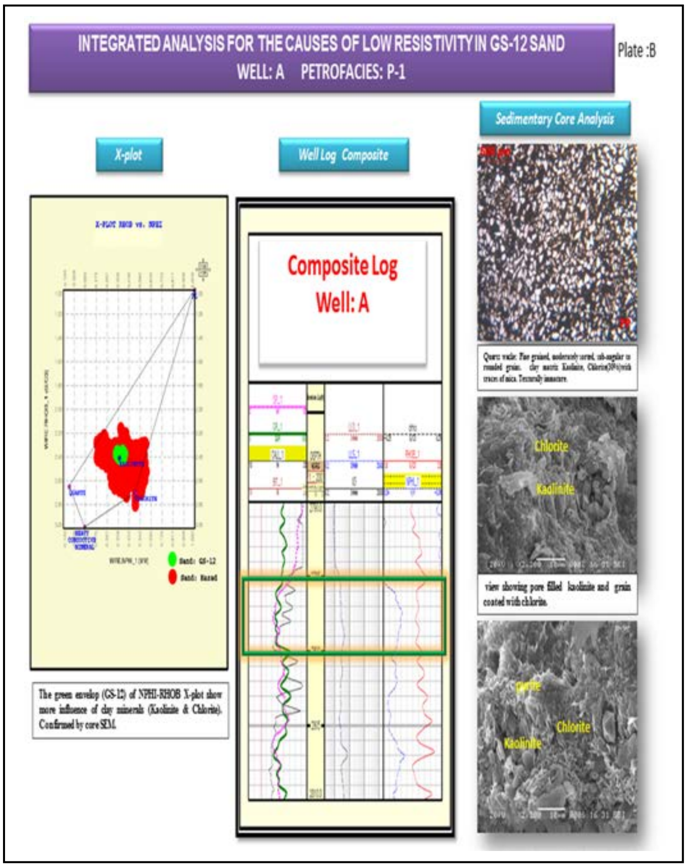


Plate: C

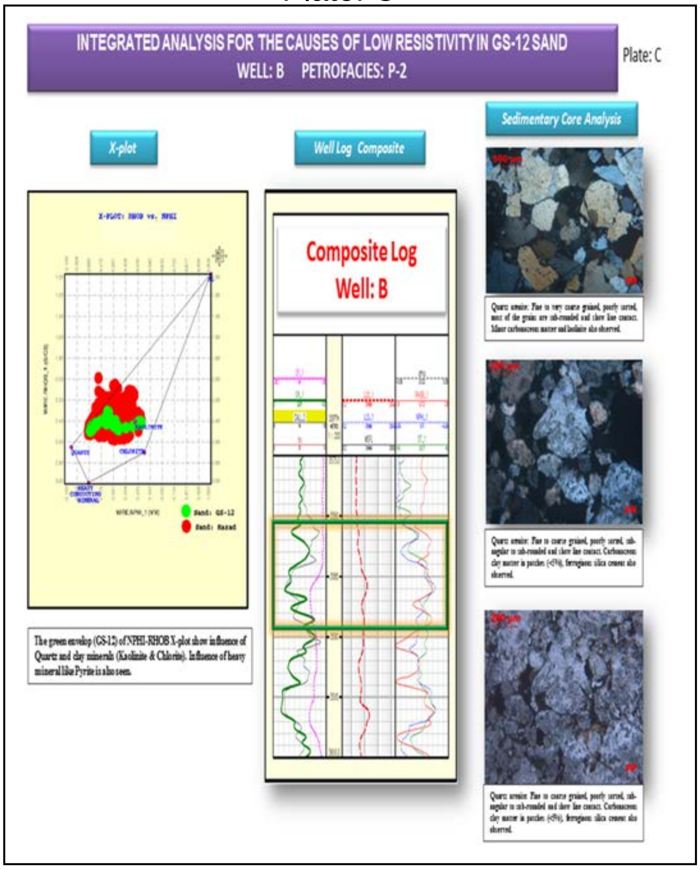


Plate: D

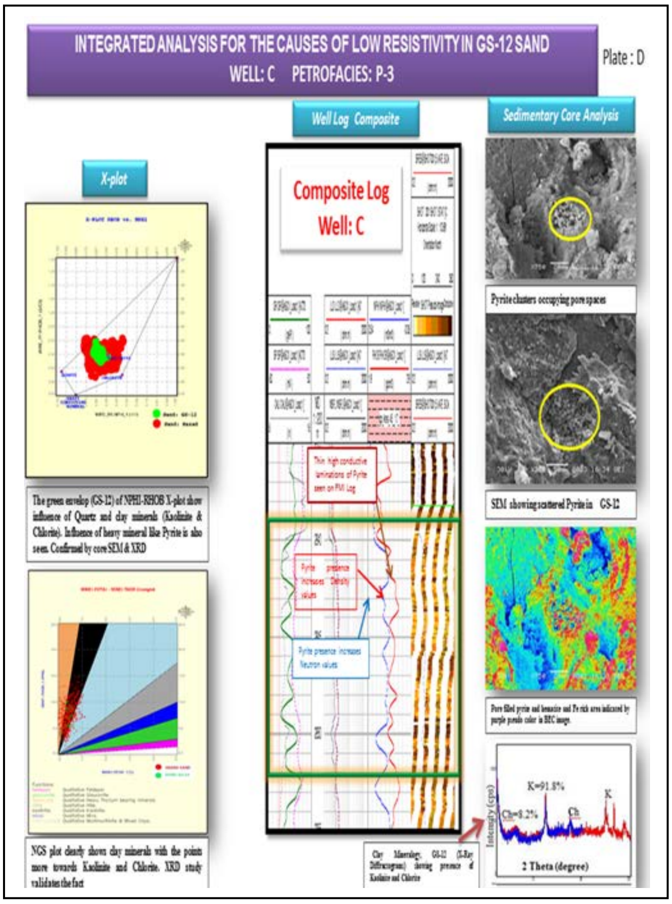
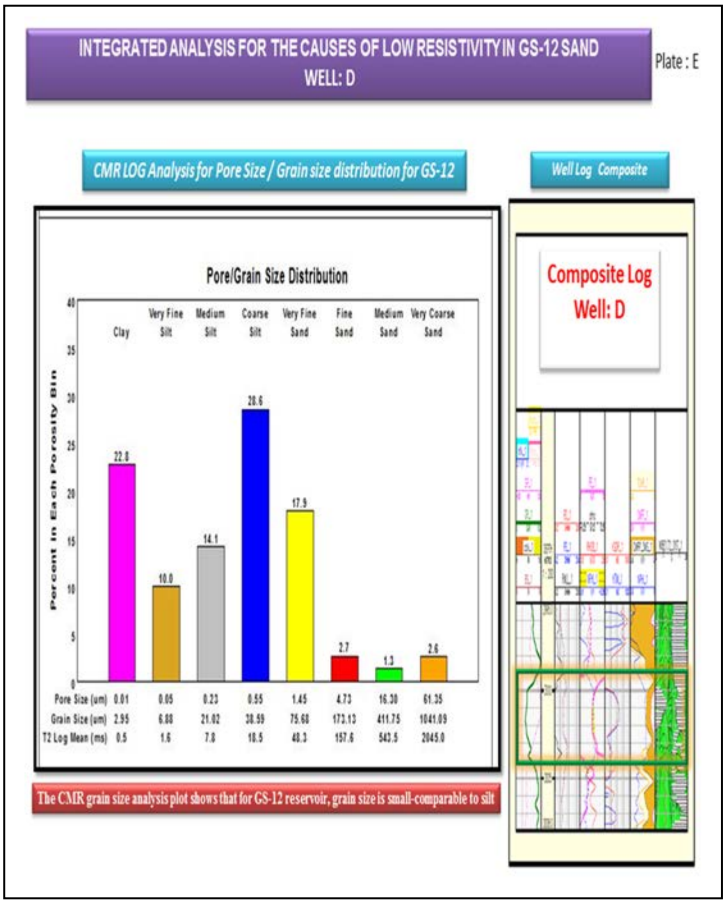


Plate: E



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