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The low resistive Tertiary clastic reservoirs in KG Basin, India a challenge towards Hydrocarbon Explorations

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Summary

*The Krishna-Godavari Basin, a passive continental margin located on the east coast of India having NE-SW structural trend. The recent oil and gas strike in **G2PA** from Godavari Clay sequence in deep offshore has given impetus for present analyses. The objective of the present paper is to address the cause for low resistivity of the pay sands within younger sequences like Godavari Clay (Plio-Pleistocene) and Ravva (Mio-Pliocene). Evaluation of such low resistivity pay sands is a major challenge as these are often overlooked owing to inherent limitations on the resolution of logging tools and unavoidable cut-offs in the estimation of reservoir parameters. Any hydrocarbon bearing layer with <3 ohm-m is called low resistivity pay.*

*Well cutting/core data in G2PA, G-1-A, G-4-B, G-4-C and other fields like A-1has indicated that the **Godavari Clay** sequence is a massive, unconsolidated, **mudstone / clay** with incipient compaction and **fine silty sand**. The underlying formation i.e. **Ravva** is a dominant **sandy sequence** with intervening shales.*

*Sedimentary features include hemi pelagic / colloidal clay nature, massive thick bedded mudstone/clay and oversized mudstone rafts, mm scale parallel lamination and thin discrete sands in **Godavari Clay** and massive sandstones, mud rich conglomerates, rhythmic occurrence of sand/mud rich layers, steeply dipping discordant bed forms and sharp bounding contacts are diagnostic in **Ravva** Formation.*

The sedimentary attributes collectively indicate muddy / sandy debris flow under dual flow sedimentary process in shelf - slope depositional setting. Foraminiferal evidence in these wells has indicated outer shelf to bathyal environment. Log motifs furnish mostly as sub marine channel sands, channel-levee complex. Resistivity of these sands range between 1.5 and 4 ohm-m. Matrix in these younger reservoirs is dominantly montmorillonite with subordinate mixed layers.

The causes for low resistivity in these sequences may be an inter play of multiple factors such as -Bed thickness, the depositional system and its geologic age, good presence of heavy mineral like pyrite, being generated by marine diagenetic processes, presence of expandable clay mineral like montmorillonite and mixed layers and high formation water salinities. Such shaly - sand reservoirs, a realistic multi -mineral combination would help assessing reservoir geology for optimizing reservoir parameters in turn volumetric estimates. As vast area in KG Basin is yet to be explored, predicting reservoir facies within the time frame tuned to the resolution of biochrons with seismic would definitely result in new hydrocarbon finds.

***Keywords:** Low resistivity anomaly, Godavari Clay, Deep water depositional system, Krishna-Godavari basin (KGB).*

Introduction

The recent oil and gas strike in **G2PA** from Godavari Clay sequence in deep offshore has given impetus for present analyses in Krishna-Godavari Basin. The objective of the present paper is to address the cause for low resistivity of the pay sands within younger sequences like Godavari Clay (Plio-Pleistocene) and Ravva (Mio-Pliocene). Evaluation of such low resistivity pay sands is a major challenge. Any hydrocarbon bearing layer with < 3 ohm-m is called low resistivity pay. The basin presents multiple tectonic events in its evolution with unique petroleum systems through Permian to Pliocene. Active progradation of delta in Tertiary period has resulted in deposition exceeding 5000m thick sediment in offshore acreages. It is essentially a rift and clastic dominant basin. These younger formations are clearly manifested by sediment loading vis-à-vis shelf edge collapse by growth fault mechanism, toes thrust and block tilting.

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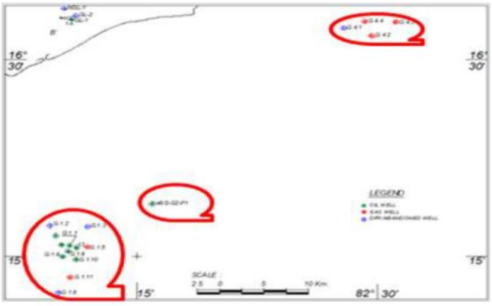

Fields studied

Core visuals showing thin parallel lamination of sand – shale / secondary pyrite mineralization along bedding plane. Shales are thick bedded, massive with very thin sand lamina: CC1, Int. 2149.2-2152.15m, G-4-C

Couplets of rhythmically bedded sand-mudstone alternations G-1-I

Figure-1: Location map of studied area and few sedimentary features depicting nature of sand-shale sequence

Methodology and Result

An attempt has been made in the present study to identify and present the hydrocarbon potential of these low resistivity pay sands from youngest sequences by using geological data such as well cuttings, cores and swc and open hole logs.

Well cutting/core data in G2PA, G-1-A, G-4-B, G-4-C (fig.1) and other fields has indicated that the **Godavari Clay** sequence is a massive, unconsolidated, **mudstone / clay** with incipient compaction and **fine silty sand**. The underlying formation i.e. **Ravva** is a dominant **sandy sequence** with intervening shales (Yadagiri, 2012).

Sedimentary features include hemi pelagic / colloidal clay nature, massive thick bedded mudstone/clay and oversized mudstone rafts, mm scale parallel lamination and thin discrete sands in **Godavari Clay** (fig.1) and massive sandstones, mud rich conglomerates, rhythmic occurrence of sand/mud rich layers, steeply dipping discordant bed forms and sharp bounding contacts are diagnostic in **Ravva** Formation. These sedimentary attributes collectively indicate muddy / sandy debris flow under dual flow sedimentary process in shelf - slope depositional setting. Foraminiferal evidence in these wells has indicated outer shelf to bathyal environment. Log motifs also furnish mostly as sub marine channel sands, channel-levee complex. Resistivity of these sands range between 1.5 and 4 ohm-m. Matrix in these younger reservoir sands is dominantly smectite with subordinate mixed layers.

Geologically these sequences are under compact and unconsolidated. Very often, their low resistivity is an exploration concern, in sensu stricto for two reasons i.e. i) the reservoir's actual water saturation is higher but free hydrocarbon is being produced. Mechanism involved for high water saturation could be micro porosity and ii) those reservoirs calculated water saturation is higher than true water saturation (Hamada et al, 2000, Dwivedi, 2001). In such reservoir mechanism involved could be the presence of conductive minerals likes clay mineral (smectite) and authigenic pyrite. Resistivity must be corrected to nullify the effect of these conductive minerals to a satisfactory level in deriving realistic reserve estimate.

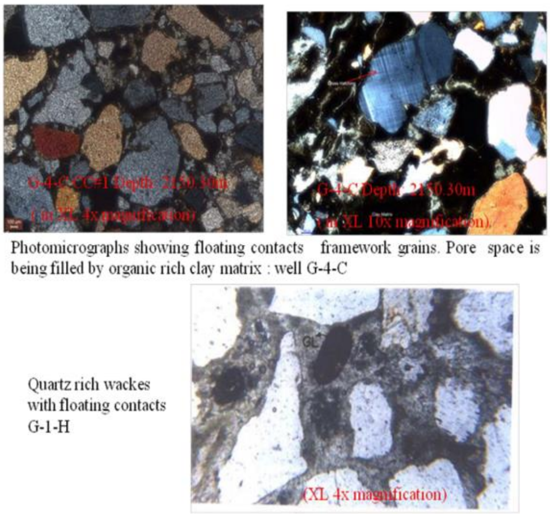

Figure 2: Photomicrograph depicting nature of micro-facies of pay sands in wells G-4-c and G-1-I

It is very often, observed in petrographic evaluation and high resolution tools like x-ray diffraction and SEM imageries that reservoir sands in offshore wells of KGB found to be endowed with fair amounts of authigenic pyrite and rich in montmorillonite either as matrix in the reservoir sands and / or associated underlying/overlying clays (fig. 3 & 4) (Yadagiri et al, 2001). The stratal relationship, sedimentary structures and foraminifera suggest gravity flow processes found to be dominant, wherein coarser clastics were deposited in during relative sea level fall as LST followed by progressive rise in sea level favoured pelagic clay deposition rich in globigerina. Quartz rich pebbly sandstones, mudstone rafts associated mega and micro fauna are certainly manifested from reworking and re- sedimentation rather than regular turbidity currents is the rule.

The causes for low resistivity in these sequences may be a combination of factors such as – i) Bed thickness i.e. thick bedded mudstone and very thin fine sand, occasionally coarse to pebbly. Sand bodies are very discrete, fine grained, silty and very thin bedded. It appears that the resolution of resistivity tool being masked by thick beds of

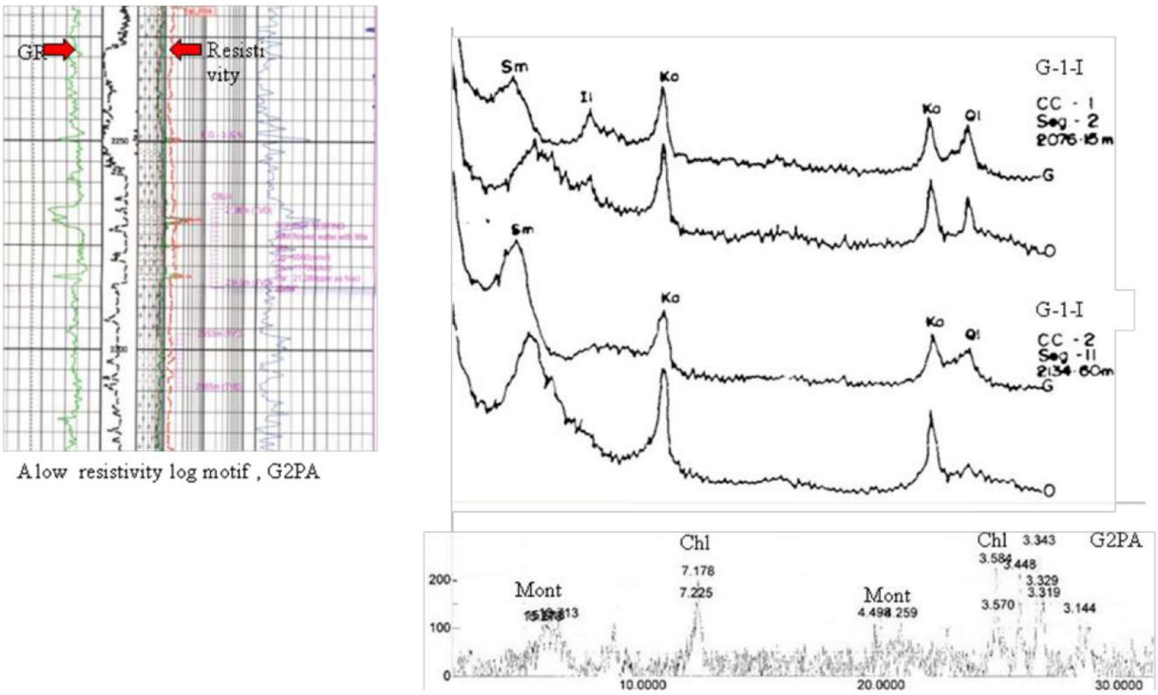

Figure 3: Low resistivity response is due to abundant smectite and chlorite

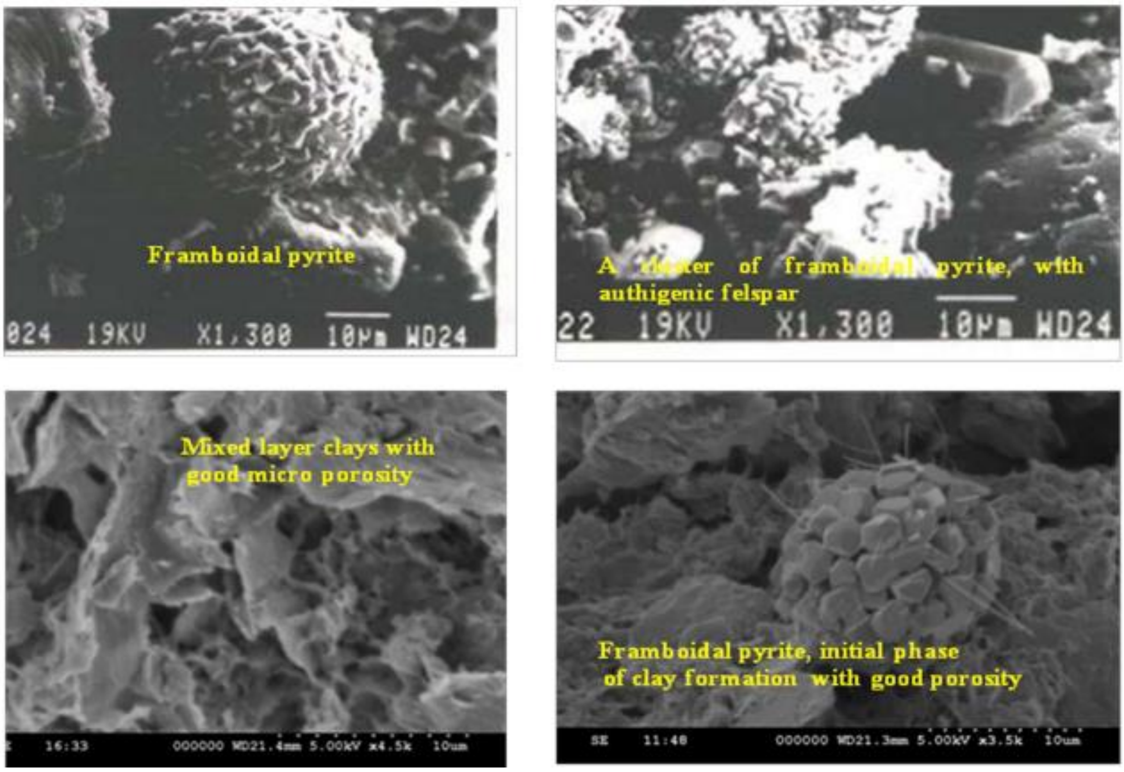

Figure 4: SEM imageries clearly depicting the cause of low resistivity is due to authigenic pyrite, montmorollinite and mixed layers like chlorite-montmorollinite

mudstone ii) The depositional system and its geologic age is critical as these laminar / colloidal clays inter bedded with very fine to rare pebbly sand type lithology reflecting dual flow regime characterized by changes in energy levels iii) Good presence of heavy mineral like pyrite, being generated by marine diagenetic processes definitely playing a critical role in subduing the resistivity response amongst these reservoirs iv) Presence of expandable clay mineral like montmorillonite and mixed layers and v) high formation water salinities confirmed in tested intervals in G2PA (Object-I: 2491-2476, 2465-2438m; salinity 21.4 g/l & Object-II: 2266-2285, 2296-2308m; salinity 19.30 g/l) also substantiates above findings.

Conclusions

The causes for low resistivity in these sequences may be a combination of factors. Such shaly - sand reservoirs, needs a realistic multi -mineral approach that would help assessing reservoir geology for optimizing the reservoir parameters and volumetric estimates. As vast area in KG Basin is yet to be explored, predicting reservoir facies within the time frame tuned to the resolution of biochrons with seismic would definitely result in new hydrocarbon finds.

Acknowledgement

The authors express deep sense of gratitude to Shri N.K.Verma, Director (Exploration), ONGC Ltd, New Delhi for permission to present this paper in SPG-2013 at Kochi, India. Help received from different quarters and discussions held with domain experts are duly acknowledged.

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