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Optimized Workflow for Basement Characterization: An Indian Perspective

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Introduction

Basement reservoirs have been known about for decades but were often passed over as ‘of no economic potential’. Increase in energy demand over past few years motivates hydrocarbon exploration activities for basement reservoirs. Several methods and workflows are available to explore and characterize such unconventional reservoirs. Many fields all over the globe commercially produce hydrocarbon from basement reservoirs. Various techniques using well-logs are useful to characterize the basement reservoirs for hydrocarbon exploration.

Basement reservoirs are commonly very thick, porosity is mainly secondary, distribution of porosity and permeability is irregular and hence productivity varies greatly. The pore space in the basement rock is mainly formed through fracturing and diagenetic processes. The resulting pore structure heterogeneity makes formation evaluation extremely challenging.

Basements are composed of various minerals with complex lithology. Primarily it has poor reservoir quality. However, development of fractured zones within basement can lead to a potential reservoir quality, which can be the home for hydrocarbon in basement. Well-log methods are well established for formation evaluation of sedimentary rocks, but conventional open-hole log analysis is not adequate for fractured basement characterization. Present study emphasizes an optimized workflow for basement characterization in an Indian scenario with an example. An integrated advanced well log evaluation methodology has been adopted to address the challenges of reservoir characterization in fractured basement.

Geological Overview of India Basements

Basements are having good hydrocarbon potentials in India. There are variations of basement rocks which have such potential varying from western on-land basins of Gujarat and Rajasthan to western offshore basins in Arabian Sea of western India. In southern region, basements are good hydrocarbon producers in Cauvery Basin and Krishna Godavari Basin. Also, basements are producers in north-eastern parts of India. However, types and lithology of those basement reservoirs are not unique. There are two broad types of basements in India which are hydrocarbon producers; - basaltic and granite-gneissic. Basalts are mostly present as multiple layers in on-land basins of Gujarat, which are having fractures and potential hydrocarbon accumulations. However, in western offshore basin, there are both granite-gneisses and basalts. Basalts are geologically younger and emplaced over granite-gneisses at various areas. However, granite-gneisses are present directly below the sedimentary sequences in ridges or structural highs. Basement reservoirs of southern India are mostly gneissic in nature. North-eastern India has basement reservoirs which are primarily of granite and granitic-gneisses (after Sircar, 2004).

Workflow

Characterization of basement reservoirs is extremely challenging. Conventional open-hole log analysis is not very useful to delineate reservoir properties in basement. Matrix properties are complex in nature due to various igneous and metamorphic mineral assemblages. This leads a higher uncertainty in formation evaluation using conventional approaches. Moreover, basement reservoir does not have any primary porosity development. Fractures and diagenetic processes are the key for any basement reservoir property development. Hence, lithology determination and fracture characterization are the two key aspects of basement characterization. Also, additional information using wide-band frequency acoustic analysis can lead a critical insight for basement evaluation. Moreover, determination of variation in stress direction can be good information for delineating the fracture sets based on property variation. A schematic of this workflow is illustrated through a diagram later (Fig. 1).

Conventional open-hole log analysis gives a preliminary idea about the delineation of broad zonal variations in basement. However, as it has a higher uncertainty due to mineralogical complexities, elemental analysis from spectroscopy measurements can improve the understanding of lithological variations with confidence. Once the mineralo-facies are under control, an attempt can be made for fracture characterization. Borehole micro-resistivity imager analysis can provide a detailed analysis based on textural variations in various mineralo-facies. Determinations of fractures and bandings can be possible with high confidence. However, it will be difficult to identify open fractures based on only borehole micro-resistivity image analysis due presence of complex conductive minerals in basement. Borehole acoustic analysis resolved this uncertainty to determine the open fractures in basement, which can be the potential contributor for hydrocarbon production from basement. Detailed fracture property analysis can be carried out for those open fractures including fracture aperture, porosity and density determination along-with a possible genesis of those fractures. Those open fractured zones can also be utilized for optimized straddle packer dynamic measurements for confirmation of hydrocarbon presence.

Results and Discussions

We will be discussing an example from a well which was drilled for basement characterization in western offshore basin of India. Conventional open-hole logs were acquired with wireline after the drilling for around 400m into the basement. Based on conventional well-log analysis a broad zonation was made, however, it was not very useful for detailed basement characterization. Integrating the elemental analysis results from spectroscopy measurements provided an insight about the mineralogical variations of that fractured basement (Fig. 2). The analysis showed presence of two distinct lithology; - a silica rich with iron poor and a silica poor with iron rich. Additionally, a variable matrix grain density has been estimated, which reflected a bimodal distribution (Fig. 3A). This variable grain density log was then used for refining the density porosity. It showed around 4 p.u. difference from the density porosity using fixed matrix density values (Fig. 3B).

After gaining the confidence on mineralogical variations, borehole micro-resistivity imager analysis was used to determine the fractures and their attributes. However, it was difficult to identify the open fractures from stand-alone borehole micro-resistivity imager analysis. Borehole acoustic analysis using stoneley waveforms was a solution for this, as borehole stoneley waves causes reflections against open-fractures. Hence, using the stoneley reflection coefficients possible open-fractures were determined. A difference between a synthetic model stoneley reflection coefficient and measured stoneley reflection coefficients indicated the presence of possible open fractures. It was also found that there were no open fractures over the zones with low silica and high iron, however, the zones with high silica and low iron had open fractures (Fig. 4). Detailed fracture properties like fracture porosity, fracture density and fracture apertures were then determined for those open fractures (Fig. 5). It was found that the zones with high silica have lower rock strength than the zones with high iron proportion and low silica (Fig. 6). A wide-band frequency acoustic analysis using dispersion plot was carried out which indicated a possible genesis of those fractured formation as stress induced (Fig. 7A). Dipole shear anisotropy analysis established the maximum horizontal stress direction as north-south, which was also in an agreement with the fracture strike directions from borehole micro-resistivity imager analysis (Fig. 7B).

Conclusions

Present study established the fact that integrated formation evaluation using a few advanced measurements along with the conventional open-hole logs is the key for fractured basement characterization. In present case, lithological variations were found with presence of two prominent mineralo-facies. Silica rich zones with poor iron content were the prime zones of open fractures with lower rock-mechanical properties. Also, a wide-band frequency acoustic analysis indicated that those fractured formations were primarily stress induced and having a maximum horizontal stress direction along north-south. A quick integrated analysis in this well was used to delineate the best possible open fractured zones in basement. Similar workflow can also be used for different types of fractured basements of India and elsewhere.

Acknowledgement

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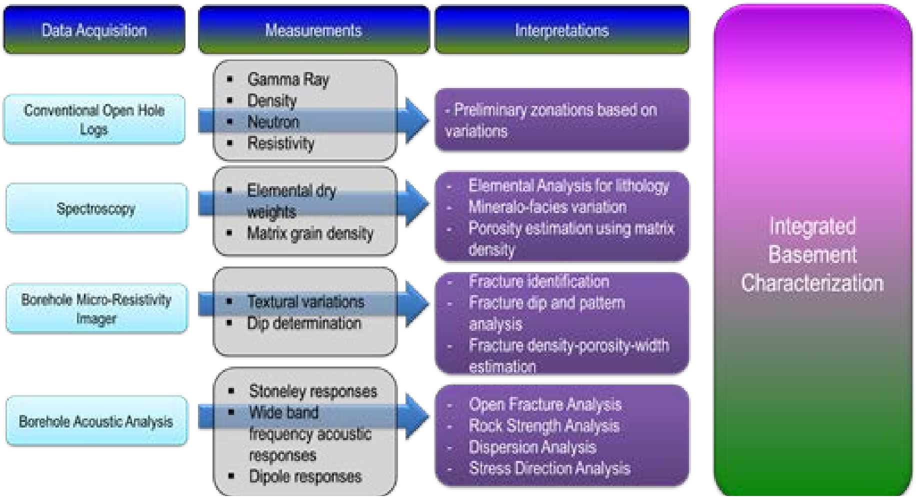

Fig 1: Workflow of fractured basement characterization

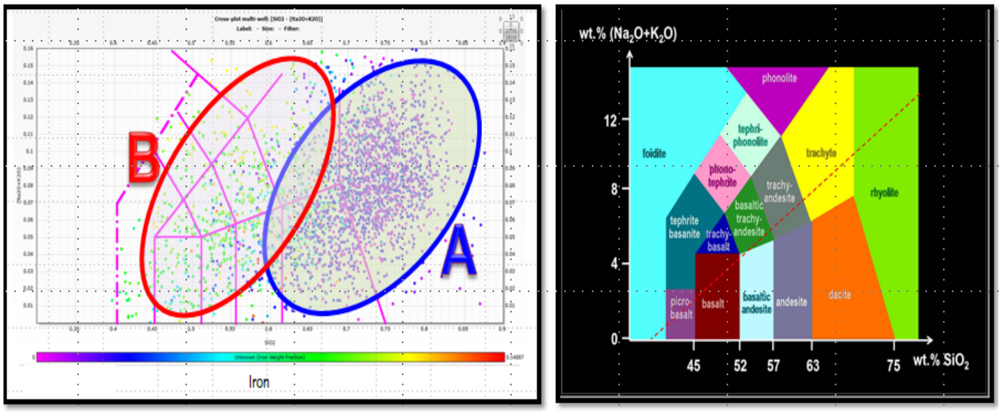

Fig 2: Elemental total alkali silica (TAS) plot for basement

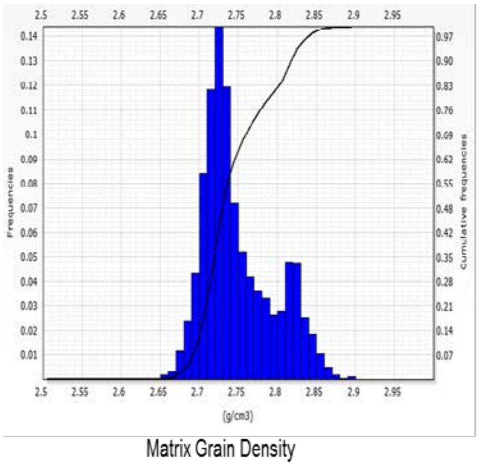

Fig 3A: Variable matrix density in basement

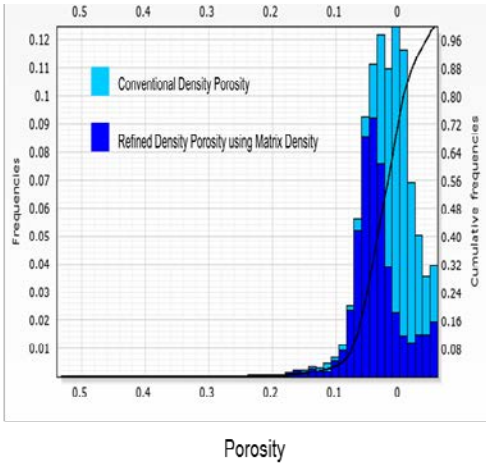

Fig 3B: Refined density porosity with variable matrix density in basement

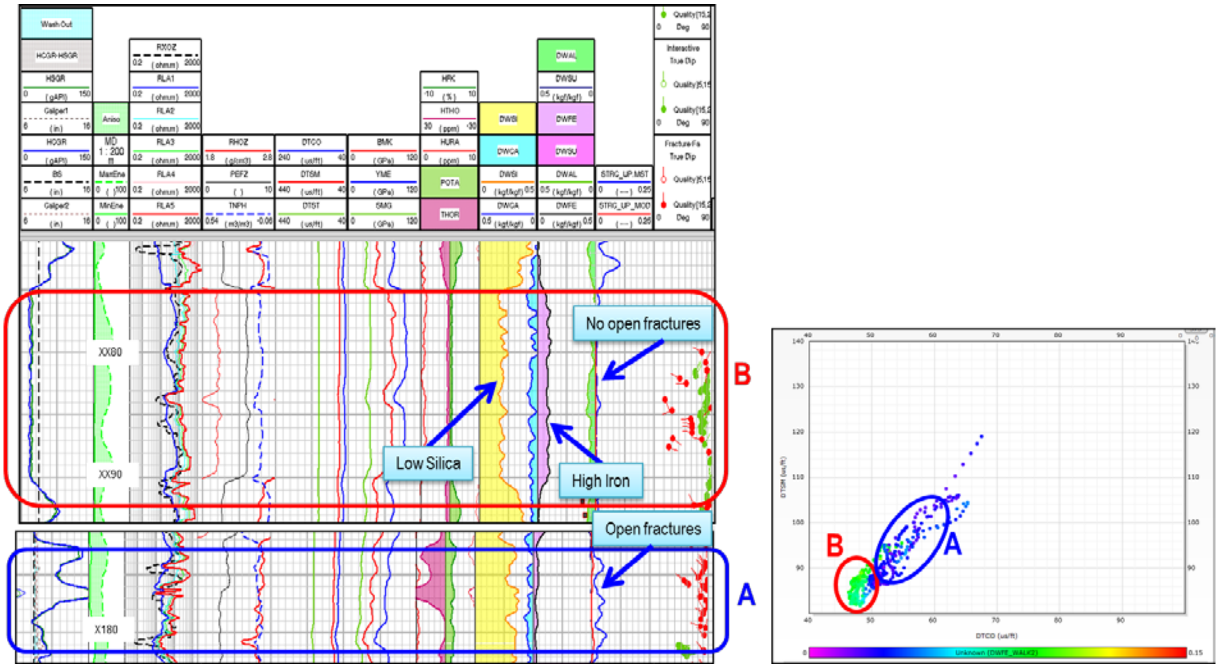

Fig 4: Integrated basement analysis using elemental analysis, stoneley fracture analysis and borehole micro-resistivity imager dip analysis. The cross plot of formation slowness shows variation with silica as colored axis. The zone marked with “A” is silica poor and the zone marked with “B” is silica rich.

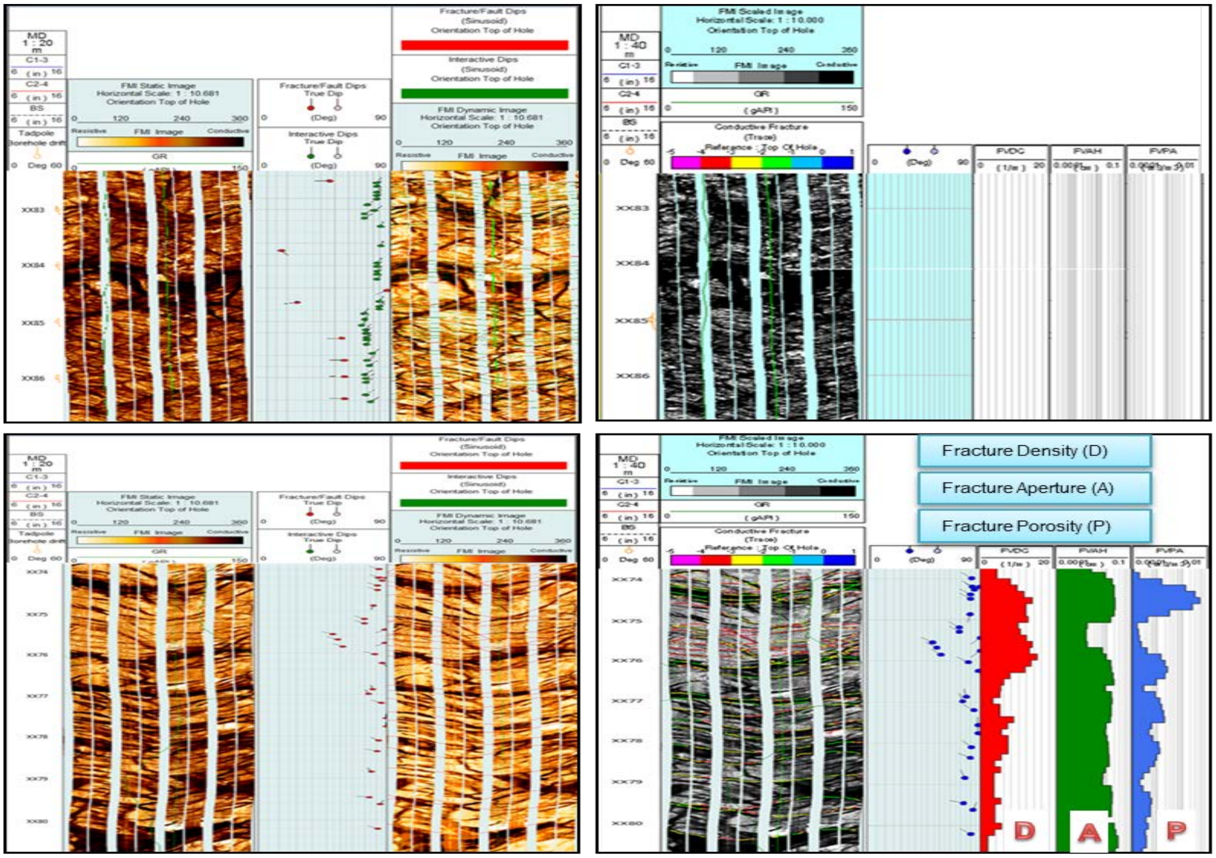

Fig 5: Detailed borehole micro-resistivity imager analysis for fracture property determination. Top zone is iron rich and low silica with bandings and no open fractures. Bottom zone is silica rich and iron poor with open fractures. Good amount of fracture density, porosity and apertures in bottom zone.

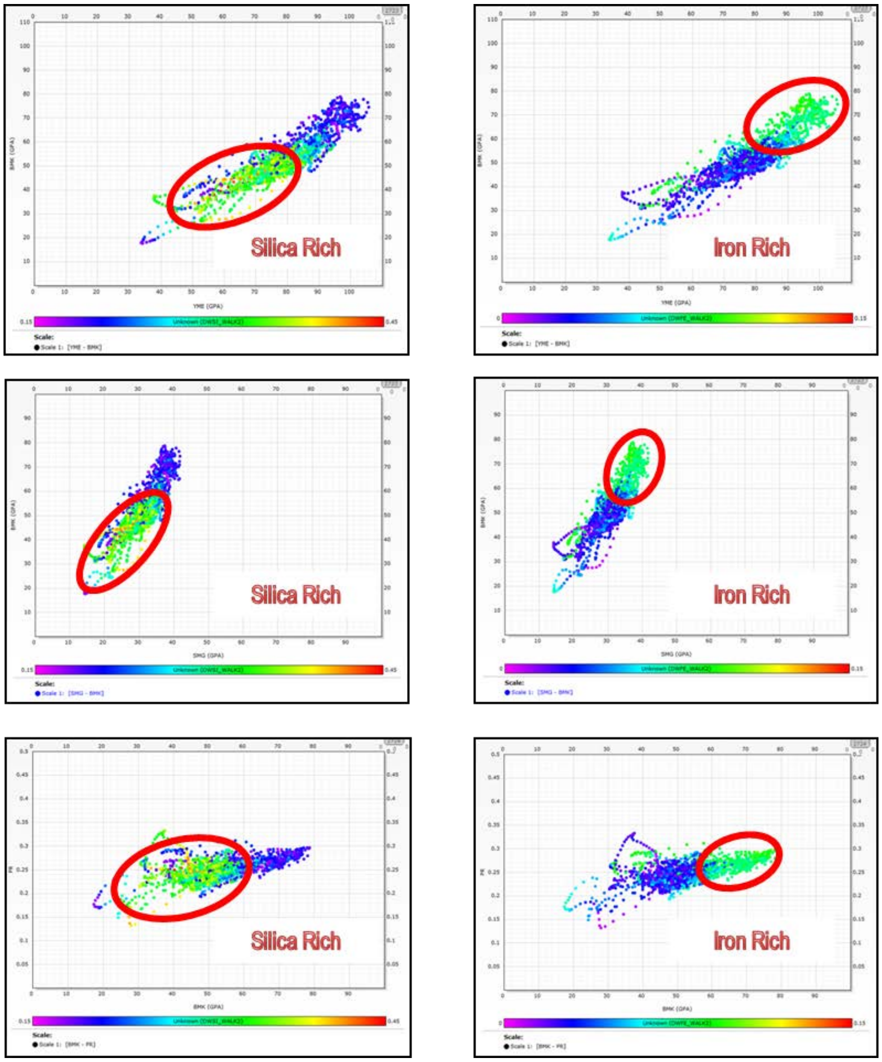

Fig 6: Rock mechanical property analysis with elemental variation in fractured basement. Top plots are young's modulus vs bulk modulus with silica and iron as colored axis. Middle plots are shear modulus vs bulk modulus with silica and iron as colored axis. Bottom plots are bulk modulus vs poison's ratio with silica and iron as colored axis.

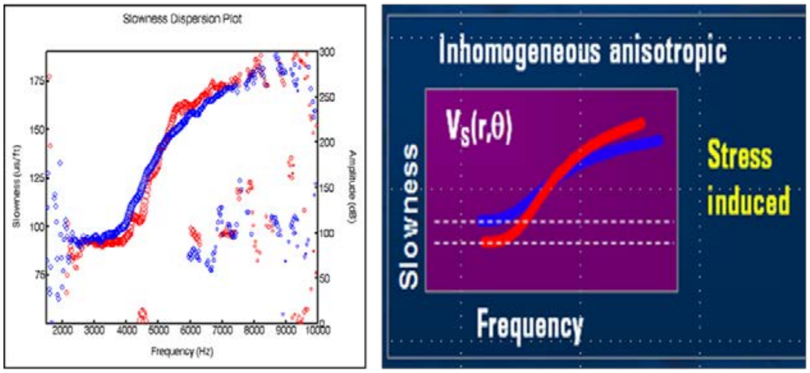

Fig 7A: Wide-band frequency acoustic analysis of open fractured zones

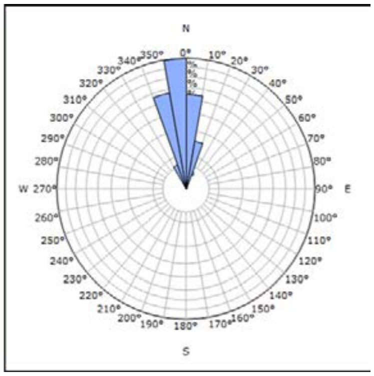

Fig 7B: Maximum horizontal stress direction of open fractures