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Characterization of Fractured Sandstone Reservoirs in Mesozoic Formation and their Hydrocarbon Prospectivity in Kutch-Saurastra Basin, Kutch Offshore, India

Abstract

Discovery of hydrocarbon in commercial quantity within Mesozoic formation (Early Cretaceous) beneath the thick traps in Kutch-Saurastra basin in the western part of India has attracted geoscientists to explore the Mesozoic sediments to fulfill the country's energy demand. These sandstone layers are subjected to multiple tectonic events and are finally terminated along an angular unconformity overlain by thick basalt flows, upon which thick Tertiary sediments are deposited giving additional over burden. The main reservoirs are Early Cretaceous tight sands which are subjected to fracturing, enhancing the porosity and permeability.

Present study is for characterization of fractures by obtaining fracture attributes from 3-D seismic data by using different techniques such as Coherency, Most Positive Curvature and AFE (Automatic fault extraction) attribute. These data are used to understand the contribution of fractures in hydrocarbon flow properties and to map fracture distribution precisely, at the field scale.

The ability to detect the presence of natural fractures in the reservoir will have a significant positive impact on the success of future wells and a better reservoir simulation

Introduction

The Kutch basin is a western margin pericratonic rift basin of India (Figure 1). The evolution of the basin is related to the breakup of eastern Gondwanaland from western Gondwanaland in the Later Triassic. The basin is characterized by dominant NNW-SSE trending faults in Tertiary section. The Mesozoic structural trends are not well observed because of poor imaging.

The shelfal carbonates were deposited during Middle Jurassic time whereas the deltaic to transitional environment influenced the eastern part of the basin. The Upper Jurassic period witnessed a regressive phase with conspicuous shift in clastic lithofacies deposition further westward overlying the Middle Jurassic carbonate. Study of lithofacies from well data reveal that Jhurio limestone of Middle Jurassic is overlain by clastic lithofacies of Jumara and Jhuran formation. The Early Cretaceous sandstones consist of huge thickness of non-marine sandstones deposited over the Jurassic-Cretaceous unconformity. The inter-tonguing of marine rocks towards the west indicates deltaic deposition under unstable sea levels. The Late Cretaceous sediments consist of mainly shelfal carbonates. However, the eastern part is covered with continental to shallow marine sandstones interbedded with thin basalt flows and shales. These Cretaceous sediments are overlain by these Basalt flows and in turn overlain by thick Tertiary sediments consisting of dominantly limestone sequence.

Recently a well, Well-A has been drilled in this area penetrating Tertiary sequences(1900m), Deccan trap(2250m) and the well ended in Mesozoics(1000m) covering 5059m of sediment thickness (Arbitrary line passing through Well-A is shown in Figure 2). Based on G&G data several objects were identified and an object in Early Cretaceous was tested and produced gas in commercial quantity (Table 1). The

pay sandstones of Early Cretaceous have been subjected to multiple tectonic episodes. However, these sandstones are very tight & poor reservoir pertaining to age and overburden pressure.

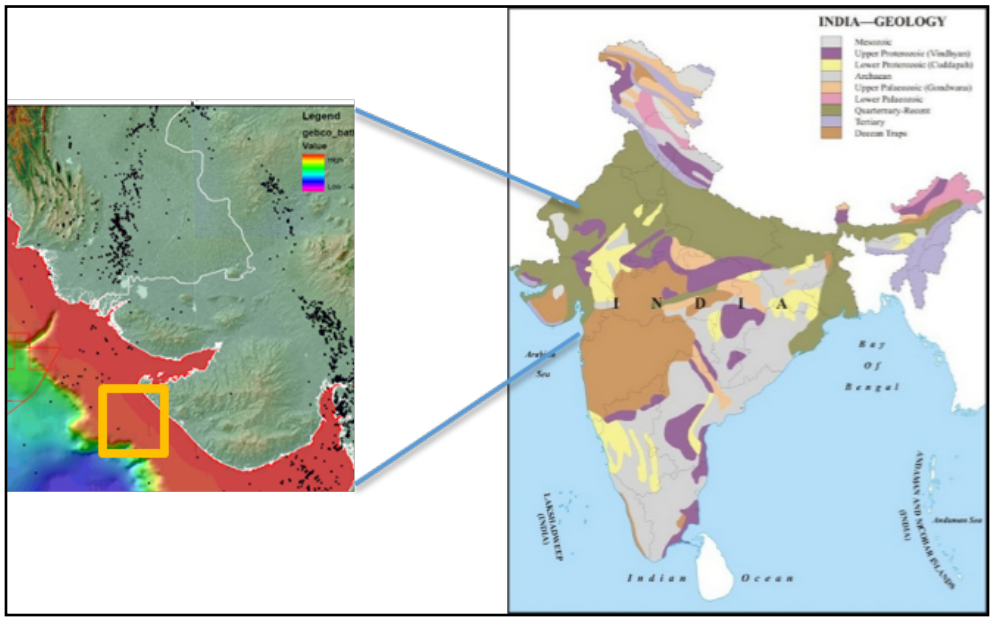

Figure 1 Location map of the study area

Table 1 Production testing results

Interval	Status	Choke Size	FTHP (psi)	GAS Rate (m^3/d)	Water rate (BPD)
Early Cretaceous Pay (36m of perforation)	Gas & Water	1/2	3750	1,56,563	4771

The Early Cretaceous object (~4400m) Produced 156563 m3/d gas from ½ " chock and 4771 BPD of water. The FTHP pressure was 3750psi (FTHP) and the temperature recorded was 1120C. MDT sample taken within the object shows 10396psi pressure, based on processed well-log data the porosity was calculated to be 8%. Whereas the permeability measured during reservoir studies was 0.8md; porosity and permeability below this huge thickness of overburden defies to produce 4771BPD water and 156563 m3/d of gas from ½" chock.

Objective

Porosity & permeability measured during reservoir studies contradict the flow rates of hydrocarbon & water obtained from production testing results. The objective of present study is to identify the reasons for such enhanced productivity of the well producing from Mesozoic clastics. Moreover, wells drilled prior to Well-A in the area didn't show such high productivity. If the reason of such high productivity could be identified and incorporated to place the wells more precisely.

Present study

Based on well log, master-log and correlation from nearby wells various formation tops were marked and were tied back to seismic. Seismic data (Beam PSDM), especially processed to enhance imaging of Mesozoic sequences, was used.

Data conditioning

The area is covered with Deccan basalt having thickness variation from 1.5 to 2.5kms. Seismic imaging in the zone of interest is very poor as (1) targeted zone is almost 4500m deep and (2) most of the seismic energy is reflected back because of the Deccan Basalt, in addition to this curvature attributes which are second order derivatives of seismic, boost the noise level which mask the geological features. The 3-D seismic volume was structurally filtered prior to computation of curvature volumes. Structural filtering was applied prior to Eigenstructure and was then used for the computation of coherency. The computed volume hence obtained was further used to compute AFE (M/S Paradigm suite of software)

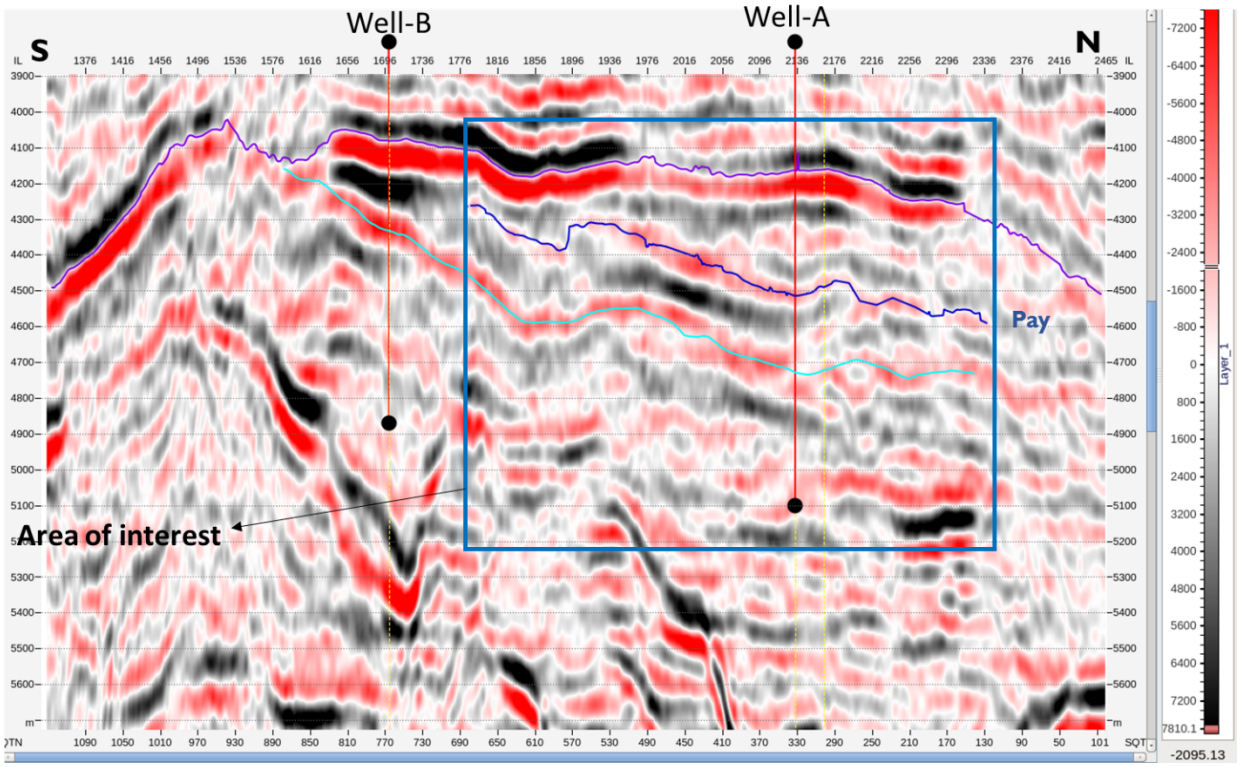

Figure 2 Arbitrary line passing through Well-A and Well-B (Horizon corresponding to pay is shown in blue)

Coherency attribute

Coherency is a measure of similarity between waveform or traces, it enhances the ability of interpreter to observe structural and straitigraphic discontinuity. A coherency slice was extracted along a window in such a way that it covers entire event corresponding to the pay. Most of the discontinuities hence obtained are oriented in NNW-SSE direction (Figure 3A) it is also observed that a discontinuity oriented in NNW-SSE direction is exactly passing through the Well-A, this discontinuity is envisaged to play an important role in production testing. Overall coherency has provided the orientation of discontinuities but the edges of such discontinuities are defined poorly. The section view (Figure 4A) of coherency is not as compelling as of its slice. To identify sharp edges of discontinuities most positive curvature was calculated in the interval covering the entire pay.

Most positive curvature attribute

Most Positive Curvature records the most positive rate of change of the reflection dip and azimuth. It highlights "frowns" in seismic reflections, or reflection bumps. As curvatures brings out discontinuities and straitigraphic feature better than coherency (given a good signal to noise ratio), discontinuities are better in terms of sharpness and consistency (Figure-3B). The orientation of discontinuities as identified by MPC (most positive curvature) is same as identified by coherency, but also, the discontinuities are more consistent. From the Figure 3B we can envisage that the Well-A is placed at NNW-SSE trending fracture. The same discontinuity can be seen in the seismic section (encircled) shown in Figure 4B.

AFE (Automatic Fault Extraction) attribute

To re-confirm the orientation of discontinuity AFE attribute was generated. AFE is M/S Paradigm's fault (discontinuity) detection technique, which generates fault surfaces from 3D coherency volume. This technique produces rough fault/fracture picks for the entire volume through a series of processing steps: line enhancement from coherency volume followed by enhancement of linear features and generates first set of probable fault sets (planar features), then it reduces duplicate and anomalous vectors, after this probable vertical fault traces are generated which are again filtered for duplicity and anomalous seed vectors and finally horizontal and vertical vectors are connected to give a unique fault (from paradigm user manual). Figure 3C shows an AFE slice extracted along the pay window shows discontinuities similar to coherency and curvature attribute and again a discontinuity(fracture) oriented in NNW-SSE direction is exactly passing through Well-A. The same discontinuity can be seen in the seismic section (encircled) shown in Figure 4C.

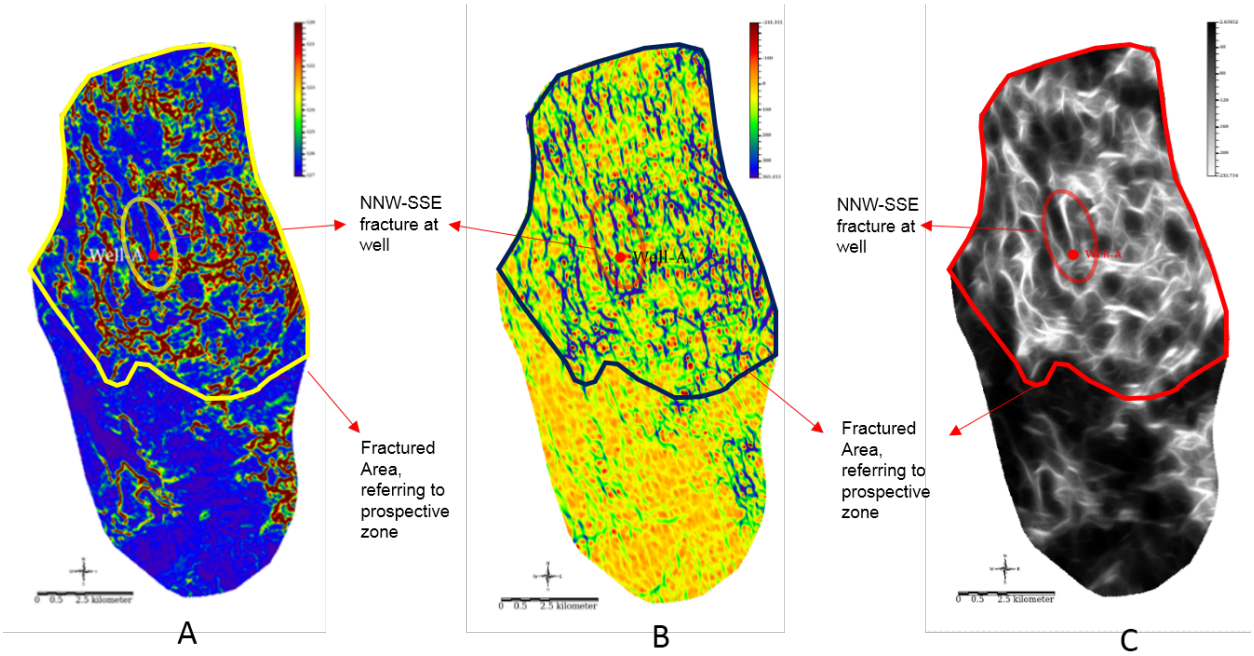

Figure 3 The window for extraction of attribute was chosen to cover the entire pay. (A) coherency (EIgenstructure) slice extracted along the pay. (B) Most positive curvature slice extracted along the pay. (C) AFE (automatic fault extraction) extracted along the pay.

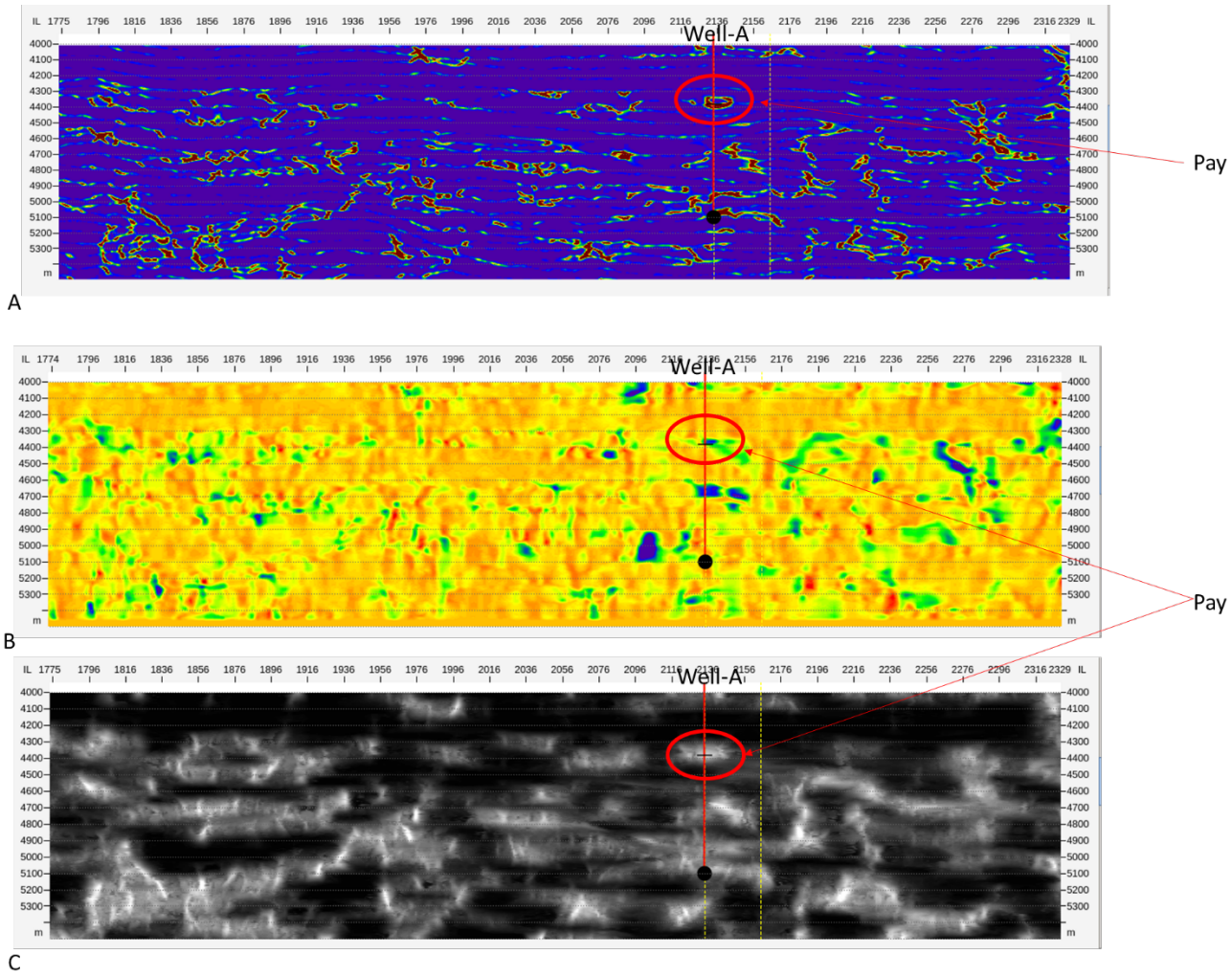

Figure 4 The pay at Well-A is circled in Red. (A) Coherency section passing through Well-A. (B) Most positive curvature attribute section passing through Well-A. (C) AFE attribute section passing through Well-A.

Observation in Well-A

During the production testing and well- log evaluation of image logs observations were made, given as follows:

- Vertical fractures were identified in the image-log, in the well, at Early Cretaceous pay having NNW-SSE orientation.
- During production testing gas beneath 4500m has replaced entire testing fluid within 20 minutes and reached to surface.
- Reservoir studies, during production testing reveals permeability of 0.8 md.
- Gas produced from ½" choke is 156563 m^3/day & water 4771 BPD.

Hydrocarbon Prospectivity

Discovery of gaseous hydrocarbon in two drilled wells below thick Basalt and commercial rates of production in the wells is a testimony of generation, migration and accumulation of hydrocarbon in tight sandstone reservoirs of Mesozoic Formation in Kutch-Saurastra basin. Figure 3 shows northern part of the area is having more fracture density and hence more prospective from hydrocarbons point of view. Identification of such fractured zones will reduce the cost and therefore improves the economics to upgrade this basin to Category-I.

Conclusion

Combining the results obtained from fracture characterization, observations of image-log, production testing details and reservoir studies followings are the conclusions obtained:

- Orientation of fracture identified by fracture characterization passing through the well is same as in well data.
- The amount of gas and water produced by well is not possible pertaining only to permeability of 0.8md, measured in pay sand.
- Arguments mentioned above confirms that there is a contribution from fracture passing through Well-A, to produce such large amount of hydrocarbon and water.
- Characterization of fractured sandstone and placement of wells accordingly may enhanced the productivity in low permeability reservoirs such as Mesozoics.

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