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Maximizing Productivity and Establishing Additional Reserves in Low Permeability Rocks though Improved Understanding of In-Situ Stress State: A Case Study from Barmer Basin, Rajasthan, India*

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Abstract

Barmer basin in NW India is a prolific hydrocarbon rift basin, which is the northward extension of the better-known Cambay basin. The Barmer basin formed as a failed intra-continental rift with imprints of multiple episodes of rifting viz. India-Africa separation (185-165 Ma) followed by India ‑ Madagascar rifting (92-84 Ma) and subsequent separation of India-Seychelles (70-65 Ma). Northward movement and subsequent collision of the Indian plate with the Eurasian plate during Miocene resulted in basin inversion. With the 2004 Mangala oil discovery, Barmer basin was established as a major hydrocarbon province having most of the reserves in the fluvial sandstone reservoirs of Fatehgarh Formation. Subsequently, as the basin matured, focus shifted to exploration of hydrocarbon in low permeability reservoirs (avg. 0.1-1 mD), where hydraulic fracturing was necessary for commercial production of such reservoirs. This also necessitated a proper understanding of the in-situ stress state of the basin, besides other geomechanical and structural aspects.

Discussion

Drilling induced deformation fabrics in an area provide an understanding of the in ‑ situ stress state. These deformation fabrics, viz. breakouts (BO) and drilling induced tensile wall fractures (DITWF) have been characterized by image logs and cores in the Barmer basin, thus providing critical information regarding borehole stability, hydraulic fracture designs in stimulation jobs for optimal fracture growth and thus increased hydrocarbon production. Detailed studies of a number of image logs from wells in the basin have suggested the presence of BO and DITWF at the same depth interval in vertical wells. Presence of both BO and DITWF at the same depth interval suggest that failure during drilling has occurred simultaneously in both compressive and tensile domains, in mutually perpendicular directions, indicating that there is significant difference between maximum and minimum principal (horizontal) stresses, which is most likely in a strike slip stress regime (Barton et al., 2009). Detailed study of the available image logs from wide azimuth of inclined wells suggest S1 and S3 to be horizontal inferring the stress state to be strike slip regime (Figure 2) and yield an orientation of SHmax of N340° to N25° (Figure 1). Seismic data interpretation has also established late strike slip movement in the Barmer basin. Positive and negative flower structures also affecting post ‑ rift sedimentary sections imply later strike slip compression and extension respectively. This result from an integrated geomechanical and structural study has been validated with earthquake focal mechanism solutions from the 2001 Bhuj earthquake, which also suggests a strike slip stress regime in the shallow crustal depths (0-10 km) with maximum principle stress oriented N-S (Mandal and Horton, 2007).

Conclusions

The importance of the study can be adjudged from established advantages such as designing well trajectories for wellbore stability keeping in mind the breakout propensity, choice of perforation strategy to design hydraulic fractures, phasing and orientation of perforating guns to minimize fracture initiation pressure, predicting the type of fracture to be created from stimulation depending upon failure mode, understanding the interaction of natural fractures and hydraulic fractures, determining the likelihood of slip along natural fractures for better hydrocarbon productivity in naturally fractured reservoirs, and better understanding of complex structures attributed to reactivation. During recent phases of exploration in the Barmer basin when the main target reservoirs were low permeability rocks, the understanding of in-situ stress states helped in increasing productivity of wells by five to ten fold by better designing of hydraulic fractures (Figure 3) with the use of 60° phasing oriented perforation guns during production testing. Determination of critically stressed natural fractures helped in well planning to target the same for better productivity in a naturally fractured reservoir in the basin. The desire to achieve better results is never ending and so is our quest for maximizing productivity of the reservoirs. Geomechanics is a helping hand in this endeavor.

References Cited

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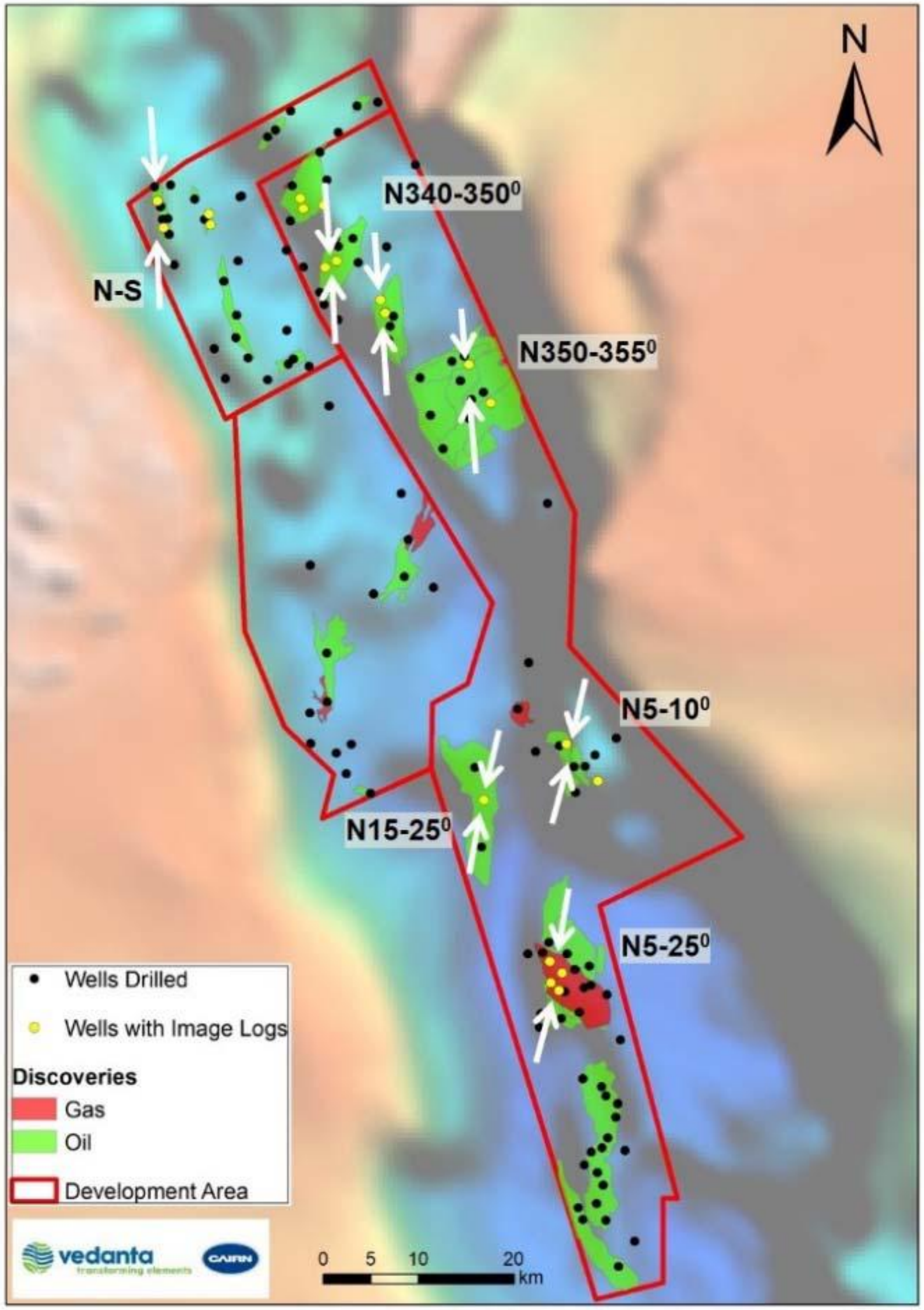

Figure 1. Regional stress map showing the direction of maximum principal stress (SHmax) of Barmer Basin.

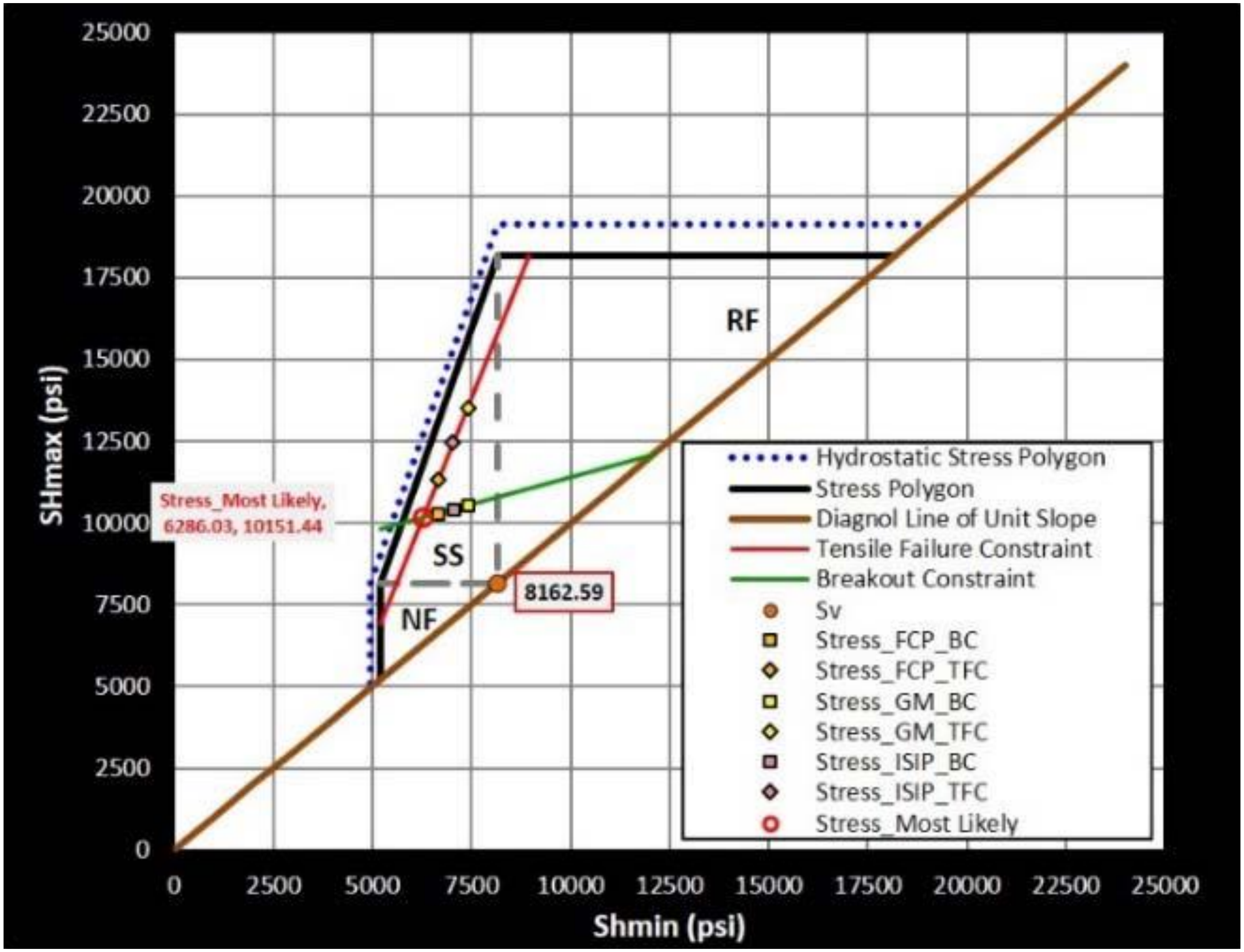

Figure 2. Stress polygon analysis of a well prior to hydraulic fracturing showing the stress state to be strike slip.

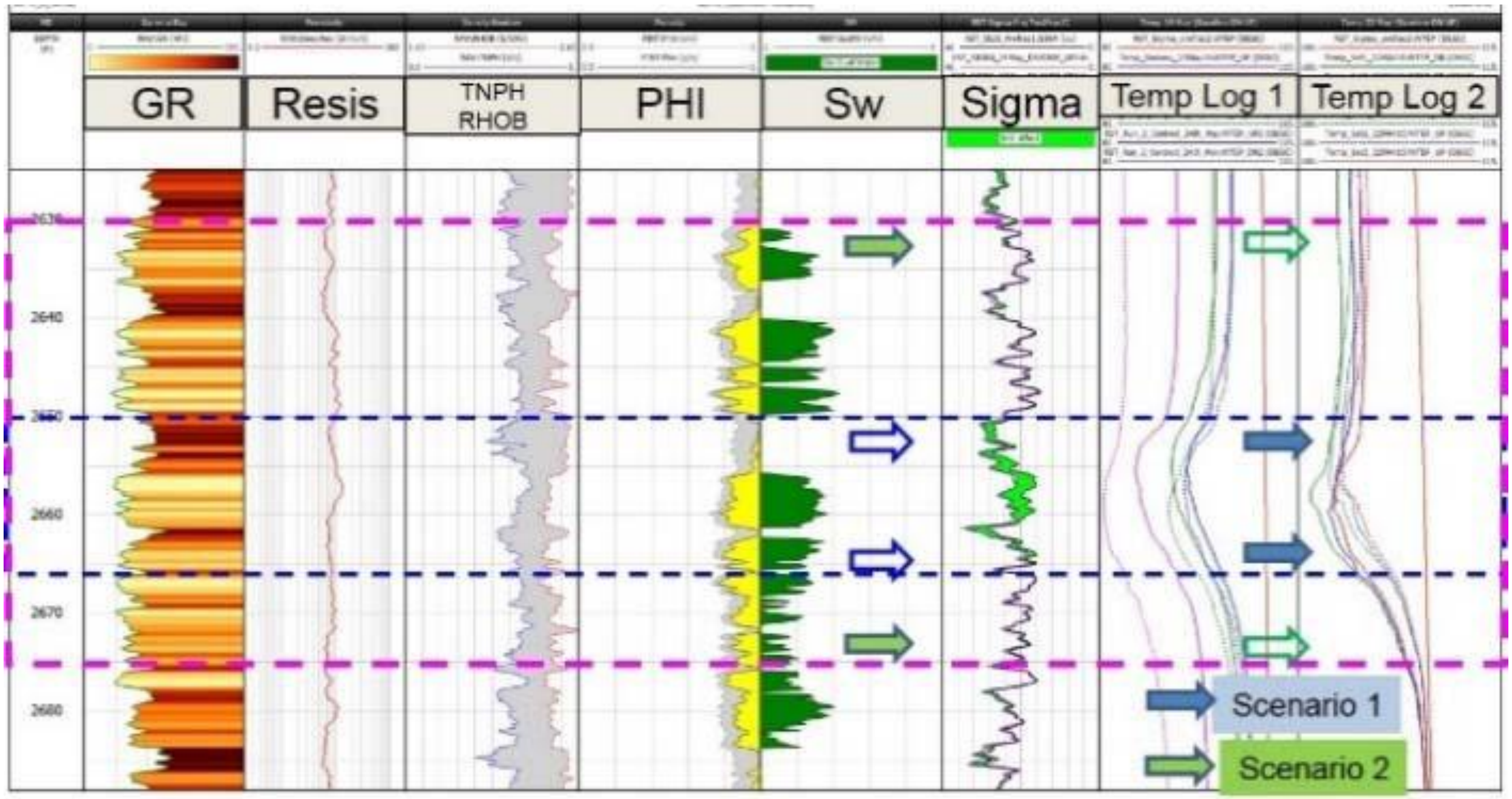

Figure 3. Log panel showing the growth of hydraulic fracture in sigma and temperature log.