Fracture Characterization and its Significance in Production from Unconventional Fractured Deccan Trap Reservoir, Padra Field, Cambay Basin, India*

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Abstract

Padra Field, located in the eastern margin of South Cambay Basin, is famous for oil and gas production from unconventional fractured Deccan Trap reservoir. More than 70 wells have been drilled in the Field, and oil gas production is from trap in the Olpad and Ankleshwar formations. It is well established that the reservoir porosity, permeability and hydrodynamic behavior in trap are attributed to natural fractures present in it. Almost all the wells producing from trap are barefoot completions (100-150 m) and are average to poor producers, and except a few wells, all are on SRP. A wide variation in well performance is observed in nearby wells in the Field, which is the primary issue for a development program and exploration.

In this article, the relationship between production character of wells and natural fracture systems is studied. Natural fracture analysis is done by utilizing field level faults, FMI logs recorded in recent wells and a few conventional cores from the trap section.

Geological Setting and Stratigraphy

The Padra structure lies in the northeastern rising flank of the late Tertiary Broach depression. The structure shows a series of NNW-SSE trending normal faults almost parallel to one another forming successive horsts and grabens resulting in a series of fault blocks and many fault closures within it. There are also some major transversing normal faults trending ENE-WSW to E-W cross-cutting the main longitudinal faults (Figure 1).

The area is covered by Tertiary and Quaternary sediments of about 600-700 m unconformably overlying the Deccan Trap. The Paleocene Olpad Formation was deposited on the Deccan Trap and consists of trap conglomerate with red and variegated claystone, trap wash, and in lower parts predominantly sand. The Cambay Shale Formation is very thin to almost absent in the area. The Ankleshwar Formation, deposited in an upper deltaic environment, directly overlies the Olpad Formation and cannot be differentiated into members in the area. In the northeastern part of the Field, post Dadhar sediments directly overlie the trap and the entire Paleogene section pinches out in this direction.

Production Characteristics

The performance of the wells in trap is mapped over the history of the Field and particularly two production parameters, initial production potential, i.e. initial production rate (IP), and cumulative production (CP), are used to understand the significance of fractures. The frequency diagrams of IP and CP for wells in the Field display a highly skewed frequency (Figure 2). The frequency distribution shows many wells with low IP and CP and a few wells with high IP and CP. This feature is characteristic of a fractured reservoir worldwide. The cross-plot diagram of IP vs CP for the trap reservoir shows a poor correlation between IP and CP as depicted by a correlation coefficient of 0.23. This aspect signifies the smaller pools with fewer wells and their drainage area are strongly controlled by localized fracture networks. These fractures are generally more dense and interconnected near the major faults zones or reservoir block limiting faults.

The IP and CP production parameters when represented in map form depict the control of major faults and reservoir block limiting faults (Figure 3). The bubble maps and contour maps for the IP and CP display the strong influence of NNW-SSW faults in the northeastern and central part of the Padra Field. In the western part of the Field higher IP and CP contours are influenced by E-W trending normal faults. More specifically, areas with closely spaced faults are the best IP and CP blocks.

Fracture Analysis from FMI

The image logs (FMI and Acoustic image logs) have become very important tools for fracture analysis as they provide vital information like azimuth, dip, density aperture, etc. of the fracture systems. This information is now widely used for geomechanical modelling of fields. In this study, FMI logs from three wells with totally different productivity behaviors are used for natural fractures and borehole failures analysis.

Natural Fractures

The FMI logs show the presence of two broad categories of trap images, one highly resistive and another conductive occurring in multiple alternate depth intervals. These two FMI characters are interpreted as fresh trap and weathered/altered trap, respectively. They may also represent the different flows of Deccan volcanism. This observation is also corroborated with cutting samples and cores from trap in the Padra Field (Figure 4).

The maximum development of conductive natural fractures is observed in high resistivity zones of fresh trap, whereas the fracture development is very poor to negligible in low resistivity conductive zones of weathered trap. The weathering/alteration of trap might have obliterated the fractures in weathered zones.

The fractures occur in minor to mesoscopic to mega sizes, and are open, as well as partially to fully filled with high resistive minerals. They are oriented in NNW-SSE and in E-W directions with true dip of 5 to 85 degrees. The smaller fractures are dipping less and occur as clusters of interconnected fractures. Larger scale fractures are isolated to a few cross-cutting fractures with sub-vertical dips (Figure 5). The fracture density is in the range 5-15 fractures/meter, the fracture aperture is in the range of 0.01-0.1 cm on image logs and true porosity is up to 0.1%.

Discussion

The occurrences and fracture density of minor and mesoscopic fractures apparently do show some influence on the well performance. The proximity of a few mega fractures/faults seems to control the hydrocarbon occurrence and increased production rates as inferred from the production characteristics of the Padra Field. The mega fracture/fault systems might be the main conduit for hydrocarbon charging of the trap reservoir block. The smaller scale natural fracture system observed on FMI logs provides porosity and permeability to the reservoir. Hence, both the mega fracture/fault system and natural fracture system are prerequisites for an ideal condition for hydrocarbon accumulation and production.

The azimuth of natural fracture sets interpreted from FMI is dominantly NNW-SSE, N-S and E-W and they more or less follow the trend of the faults in the area (Figure 6). This means the faults and natural fractures are genetically related and were developed under the same stress conditions. The related swarms of fracture systems of greatest fracture intensity and permeability will be expected around fault planes and fault offset zones. These zones of high porosity and permeability can be optimally utilized by planning wells cross-cutting the fault planes constituting the reservoir blocks at an angle of 25-45 degrees from the foot wall side to the hanging wall side (Figure 7).

Conclusions

Padra Field is unique for its oil and gas production from the unconventional fractured Deccan Trap reservoir. It contains a very critical hydrocarbon accumulation and production behavior is strongly controlled by faults and natural fracture systems. Both mega fracture/fault systems and natural fracture systems are prerequisites for an ideal condition for hydrocarbon accumulation and production. Fracture analysis of the Deccan Trap reservoir in a few wells from FMI log data suggests that a wide variation in fracture population across the Field exists due to highly compartmentalized and faulted reservoir. A genetic relationship between field level fault systems and natural fractures also exist, as they were formed in the same state of stress. This relationship can be utilized for planning infill development well locations with optimum well paths for maximum fracture intersection and further exploration of trap in the area.

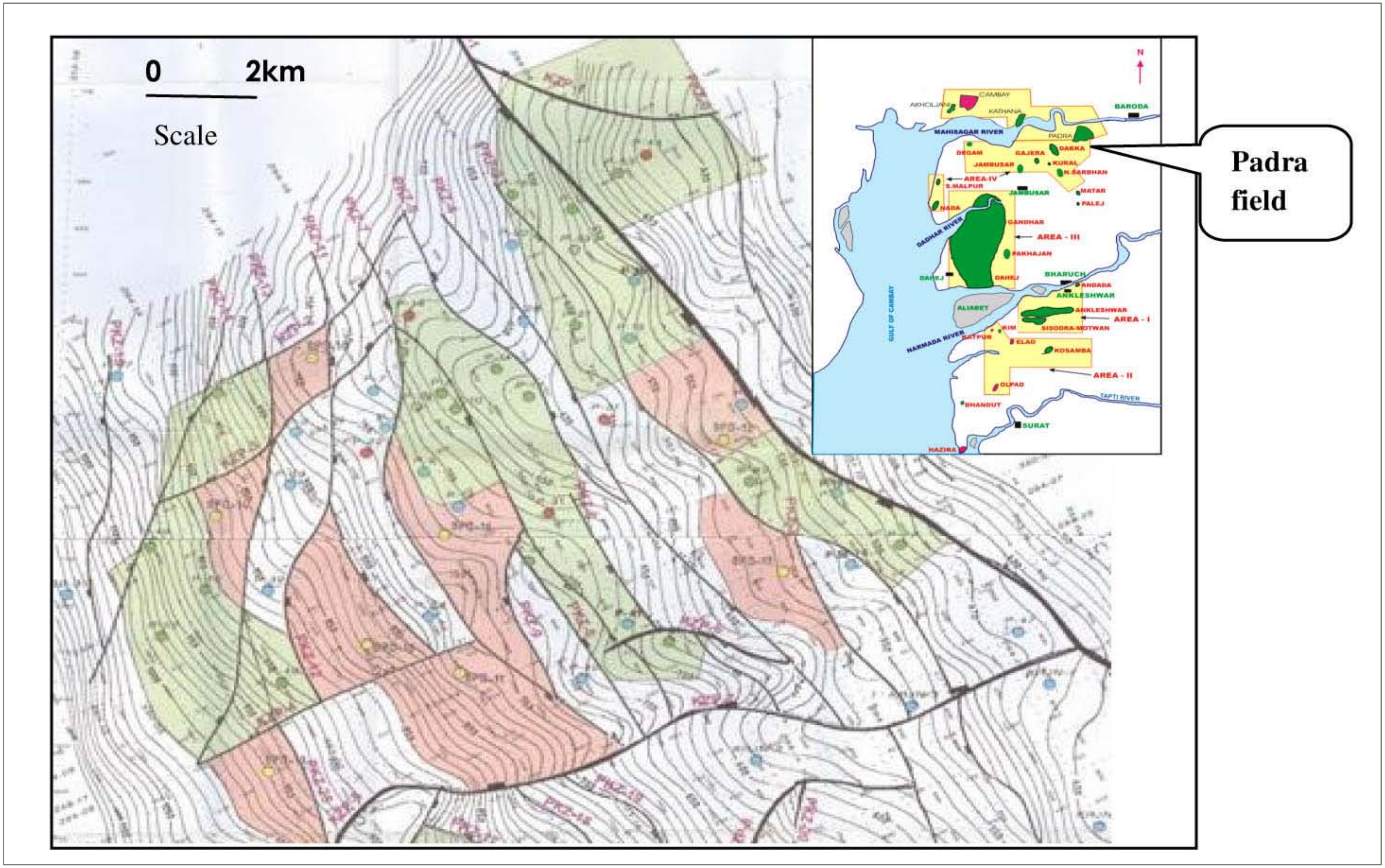

Figure1. Time structure map near the top of Deccan Trap in the Padra Field.

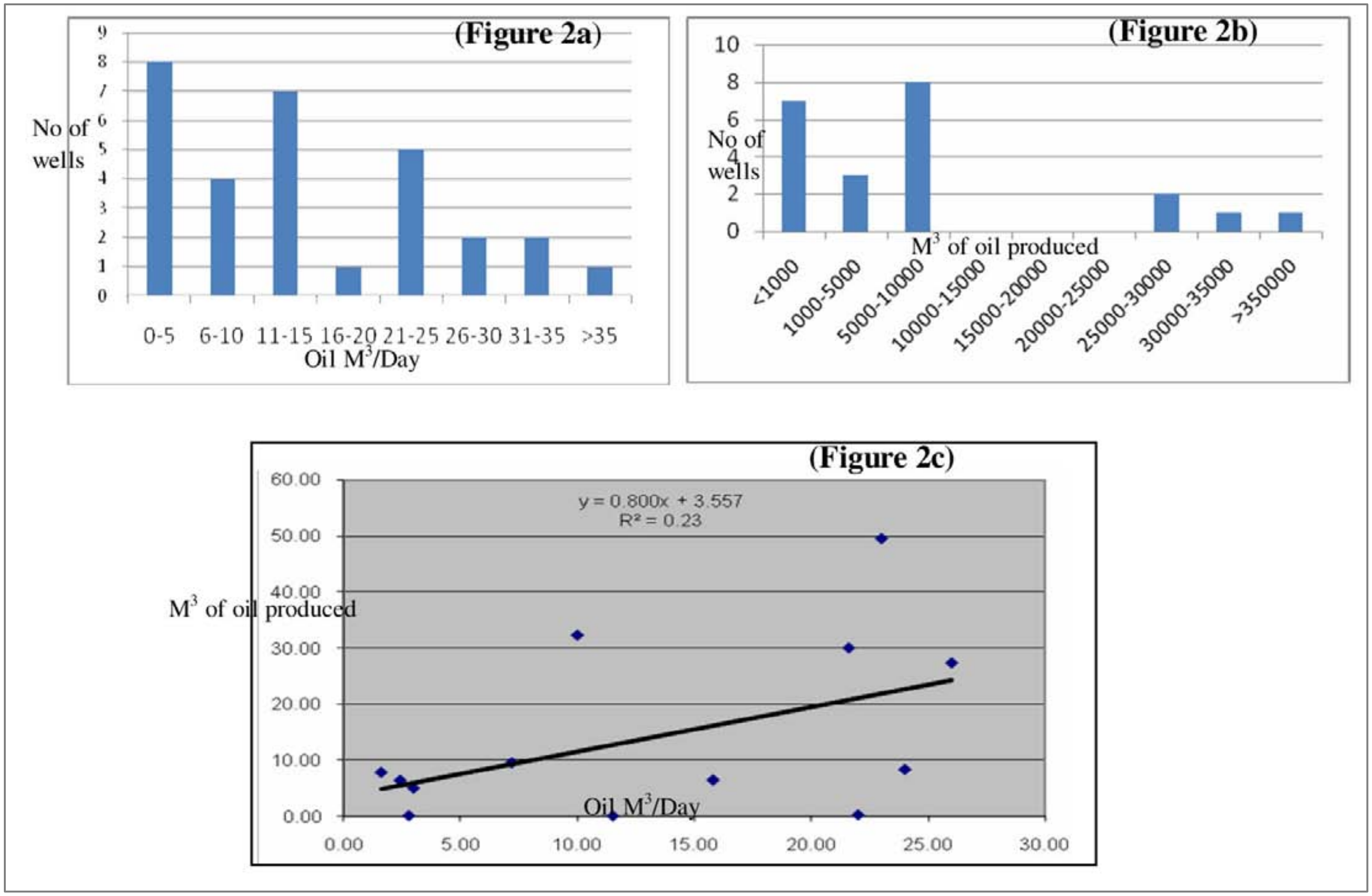

Figure 2. (a) Frequency distribution diagram for initial production shows skewness towards low production rate wells. (b) Frequency distribution diagram for cumulative production shows similar distribution. (c) Cross-plot between initial production rates and cumulative production show a poor correlation coefficient.

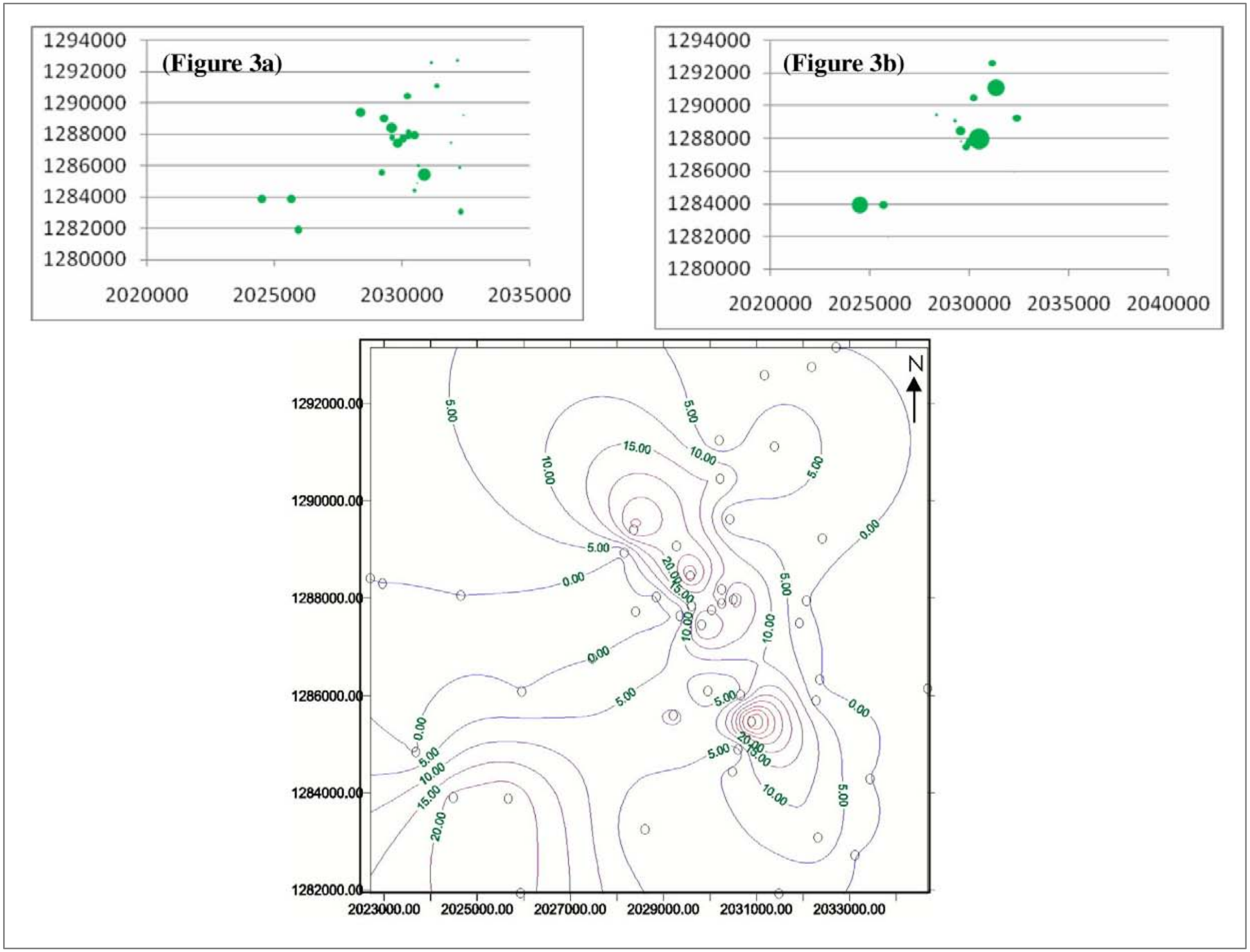

Figure 3. (a) Bubble map for initial production shows the high production rate wells along a NW-SE direction. (b) No clear-cut trend is seen in the cumulative production bubble map. (c) Contour map for initial production rate shows NNW-SSE and ENE-WSW trends, which is the result of influence of faults oriented in these directions.

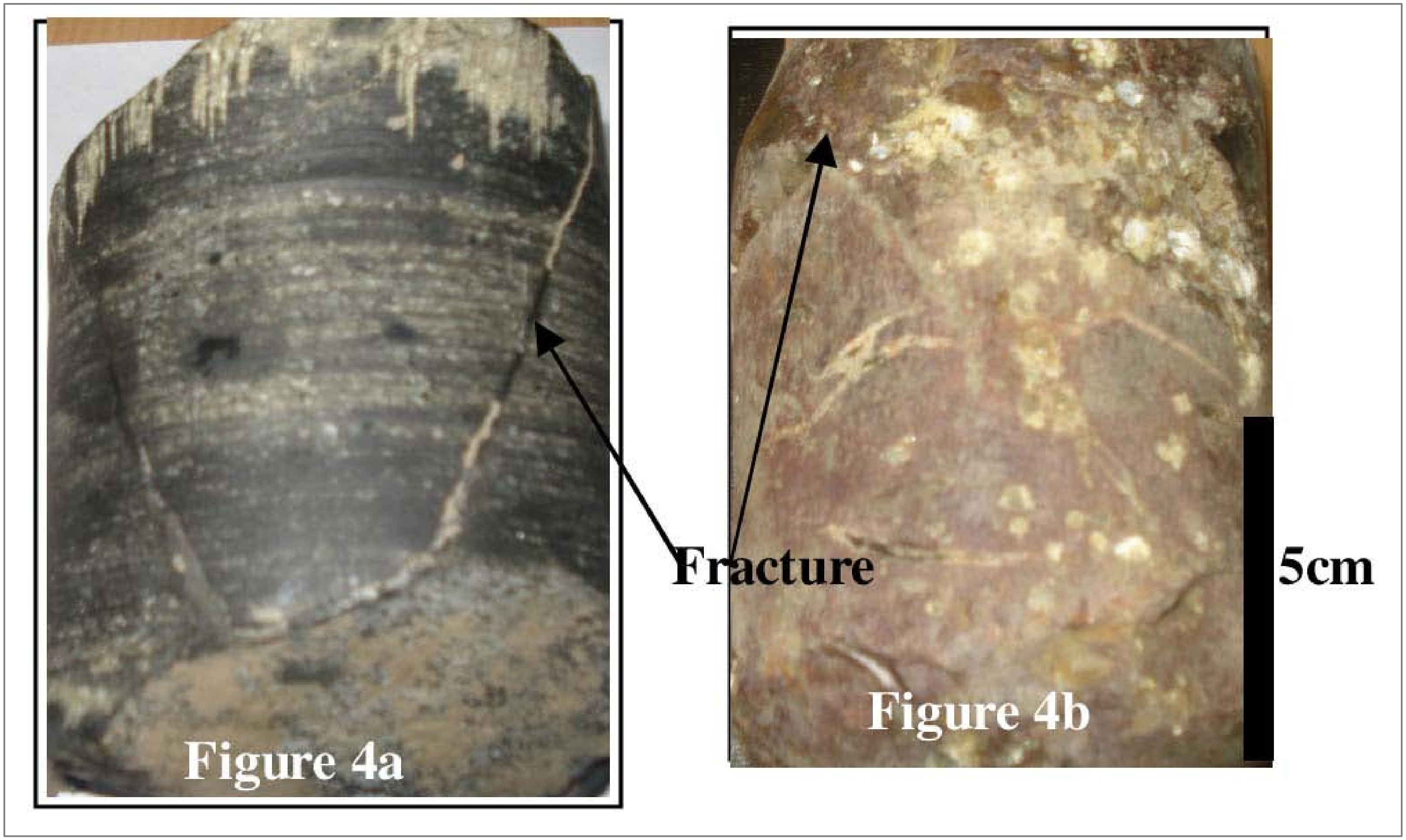

Figure 4. (a) A core section of fresh basaltic trap showing sub-vertical open fracture. (b) A highly weathered and altered basaltic core section of trap. Poorly preserved fractures and powdery calcite in vesicles are also seen.

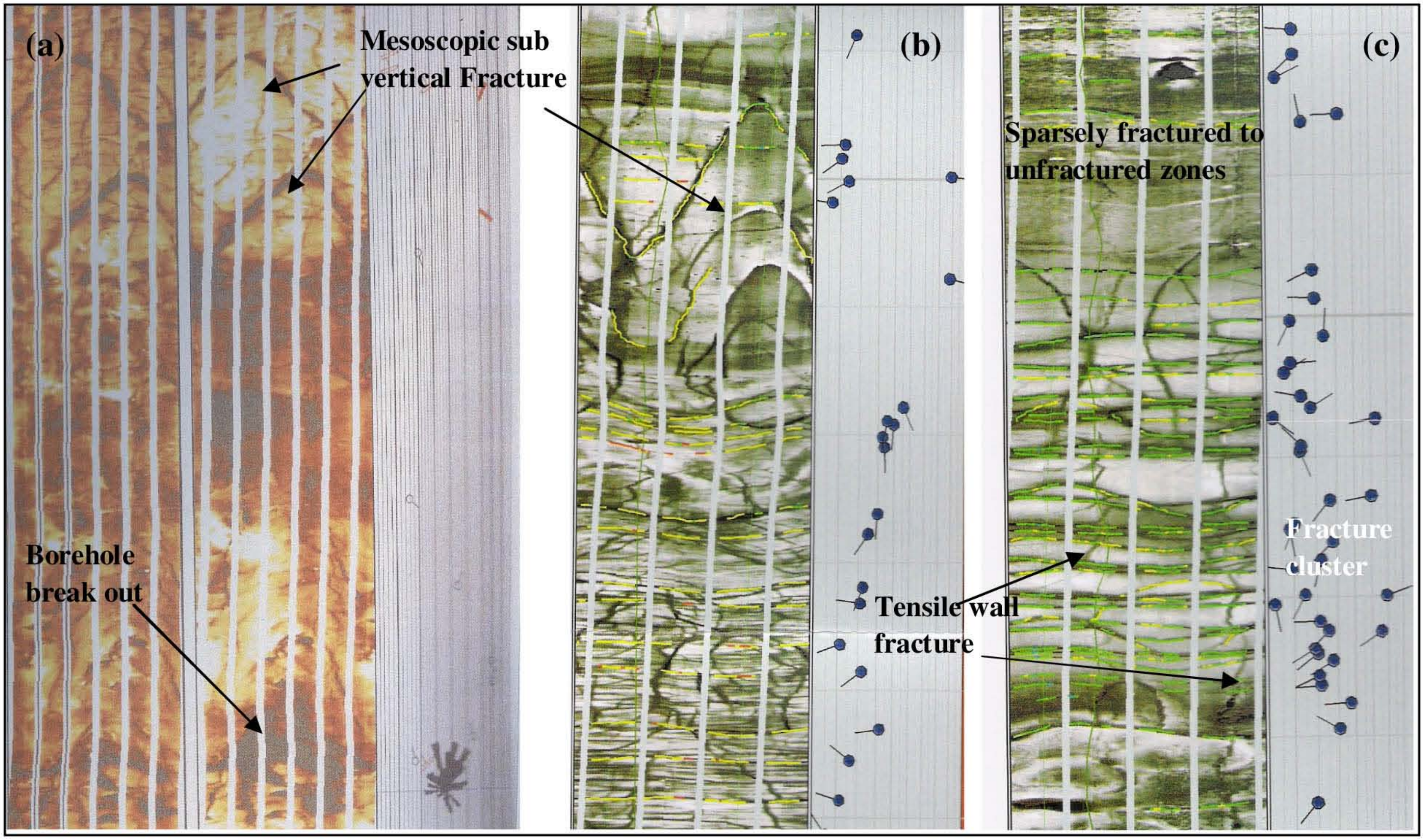

Figure 5. Examples of natural fractures imaged in two wells in trap. (a) Static and dynamic images showing mesoscopic and minor fractures. Borehole breakout is also seen due to intersection of more than one mesoscopic fracture. (b) Subvertical fractures and low-dipping to sub-horizontal fractures observed in dynamic image. (c) Fracture cluster, sparsely fractured and unfractured zones are seen. Drilling induced tensile fractures developed vertically are also seen.

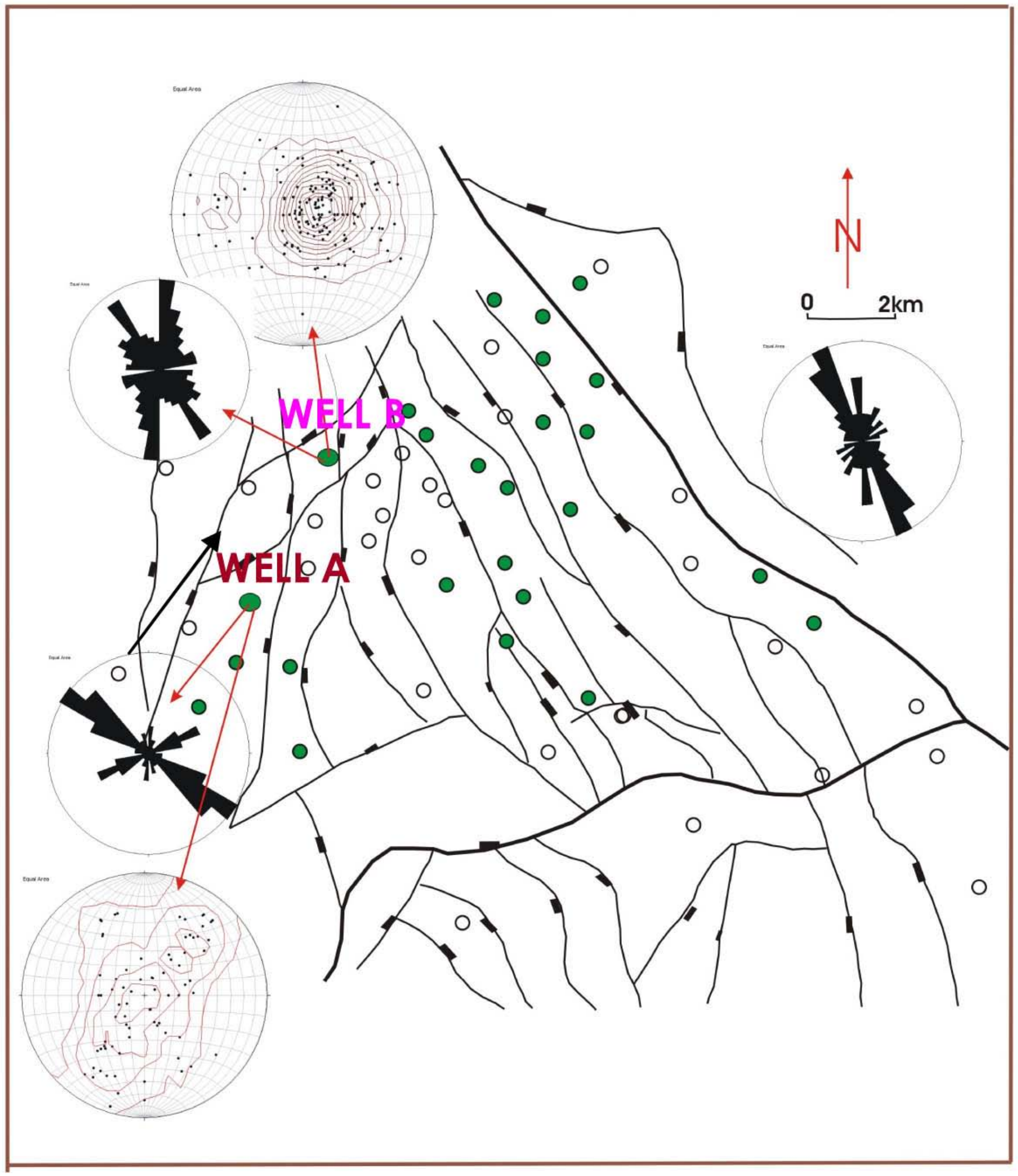

Figure 6. Rose diagram for azimuth of all fractures from wells A and B, and azimuths of Padra Field level faults show a more or less similar trend. Kamb contour of all fractures measured in these two wells suggest they intersect distinct fracture populations, indicating a highly compartmentalized faulted basement reservoir. .

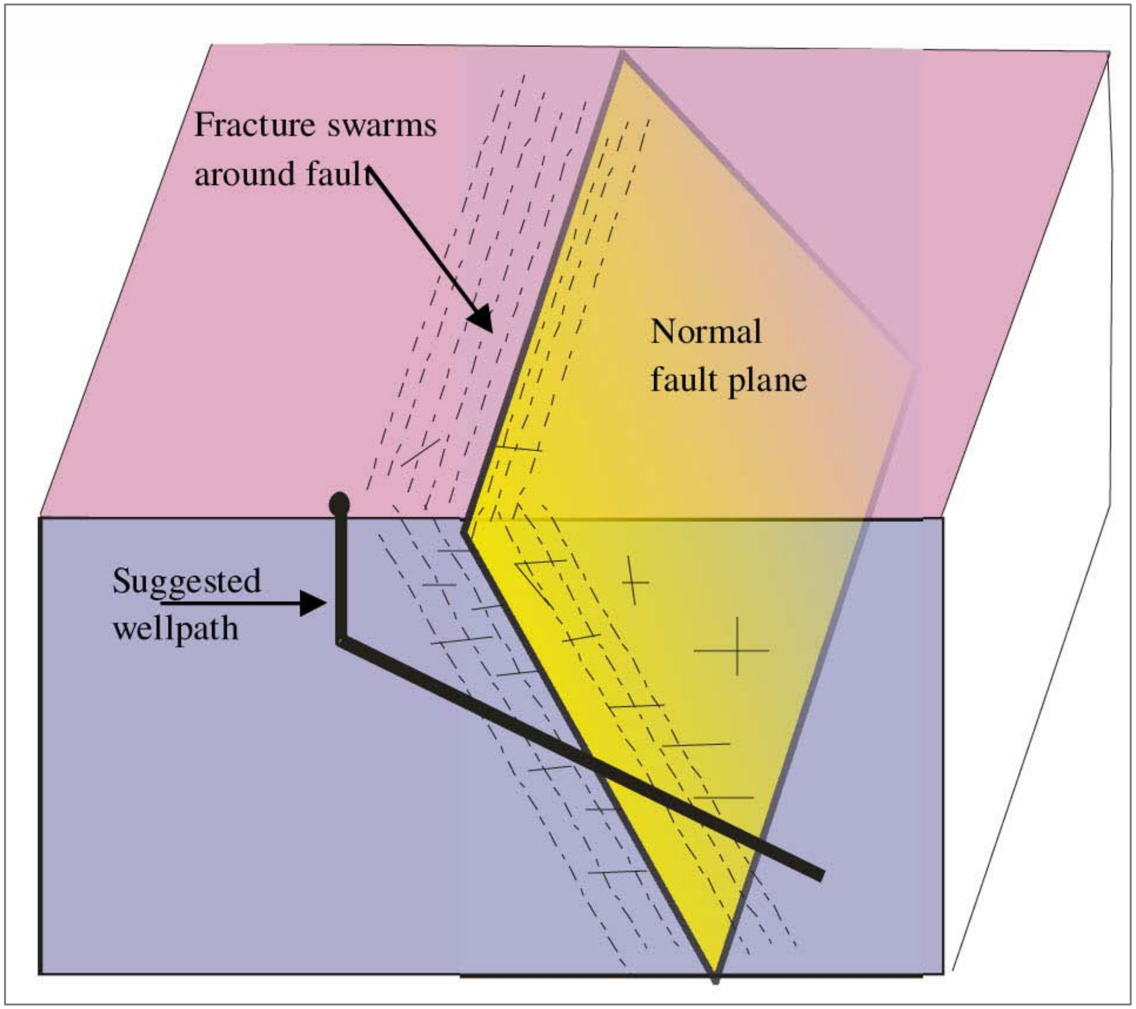

Figure 7. A schematic diagram showing suggested well path for utilizing the maximum number of fracture intersections around a hypothetical dipping normal fault plane.