Well Trajectory Impact on Hydrocarbon Discovery in Fractured Basement Reservoirs – A Case Study from Cuu Long Basin, Vietnam*

Bingjian Li[1], Wan Z. Embong[2], and Mohamed T.A. Taha[3]

Search and Discovery Article #20174 (2012)
Posted October 8, 2012

*Adapted from extended abstract prepared in conjunction with poster presentation at AAPG International Conference and Exhibition, Singapore, September 16-19, AAPG©2012

[1]Schlumberger, 2 Ngo Duc Ke St, DIST 1, HCMC, Vietnam (bli@slb.com)
[2]PETRONAS Carigali, 235 Nguyen Van Cu St., DIST 1, HCMC, Vietnam
[3]PETRONAS Carigali SDN. BHD., Level 10, Tower 2, Petronas Twin Towers, Kuala Lumpur, 50088 Kuala Lumpur, Malaysia

Abstract

The Mesozoic granite basement in the Cuu Long Basin of southern offshore Vietnam experienced several major tectonic deformations which resulted in development of multiple fracture and fault systems within. The potential productivity for each fracture set can vary significantly. Therefore, recognition of the main potential productive fracture set(s) in any given field for optimizing well trajectory plays a critical role in delivering a productive well and then impacting both exploration and development success.

In this case study, there were three exploration wells drilled to the basement in the selected field without commercial oil discovery. The existing wells include one vertical, one highly deviated in the southern part of the field and one highly deviated in the northern part. Hydrocarbon shows were detected in all wells. Prior to a new exploration well proposal in 2011, the acquired borehole images and Dipole Sonic Imagers from existing wells were studied along with dynamic data. As a result, a group of NNW-SSE sub-vertical fractures was interpreted as the dominant potential productive fracture set in the studied wells. Outcrop data from the nearby coastal area provides very useful information to better understand the fracture systems structurally. On the basis of the fracture study results, an optimal well trajectory recommendation was made for the new well. The new well, located based on 3D seismic attributes, was drilled in the southern part of the field between the two existing wells with a NE-SW well azimuth and high deviation, resulting in a successful commercial oil discovery. The case study shows that the correct well trajectory with maximized penetration of the defined

potentially productive fractures made a positive impact on the success of the new well. The experience gained from the case study has application for future exploration and development in fractured basement reservoirs.

Introduction

The studied field is located in the northern part of the Cuu Long Basin, southern offshore Vietnam (Figure 1). The basement in the Cuu Long Basin is mainly comprised of pre-Tertiary granite. It experienced several major deformations in its tectonic history, with multiple sets of natural fractures and faults formed. Weathering in the top portion of the basement, as well as hydrothermal processes, helped creation of some additional pore space within the granite in association with natural fractures and fault damaged zones. In other words, the basement reservoir was formed with the combination of various processes, including natural fracturing, faulting, weathering and hydrothermal processes during its geological history.

Exploration activity in the studied field started in the middle 1990's. Three wells were drilled for exploring hydrocarbon in both Miocene/Oligocene clastics and fractured basement. Oil was discovered in the clastics. In the basement, only minor oil flow was detected in both wells B and C, but without commercial discovery.

Well Trajectory Used in the Existing Wells

There were three different well trajectories used in the existing 3 wells (Figure 2). In the first exploration well A, it was apparently a vertical well with 400 m of basement penetration and hydrocarbon shows detected in the fractured zones. There was no oil flow in the DST. The 2nd well B was drilled at a high deviation (up to 70 degrees at well TD) with the well azimuth towards the NW. More than 770 m of basement section (measure depth) was drilled in that well. A small amount of oil (rate about 200 bbls/d) flowed to surface during the DST. The 3rd well C was drilled in the northern part of the field with a high deviation (up to 63 degrees at the well TD) with the well azimuth towards the NE. Basement penetration was about 1270 m in this well with hydrocarbon shows as well as very minor oil flow detected in the DST, with unfortunately still no commercial oil flow.

A structure map for the top basement is shown in Figure 2. The few faults in the central area of the basement high as well as the bounding faults were interpreted based on 3D seismic data. The location for the existing three wells, as well as their trajectories in map view, is shown in the map (Figure 2).

Objective for a New Well

Based on the observations of drilling results in the existing three wells, there was no doubt that the basement in the studied field was fractured and was hydrocarbon charged. However, the field will be unable to be placed in a field development plan without a firm commercial oil or gas discovery. Therefore, in 2011 a new well D was proposed to explore the hydrocarbon flow potential in the southern part of the field.

Fracture Study for the Existing Wells

In the local naturally fractured basement reservoirs, it was learned that fractures provide both permeability allowing fluid flow and part of the storage space, due to the usually tight matrix in the granite. It seems also true that there might be only a limited number of flowing (or productive) fractures or faults observed in many of the productive basement wells where PLT was run. It is crucial to understand the dominant fracture trend(s) for the potential productive fractures or faults in any particular basement field in the earlier stage of the field life in order to optimize well trajectory for better well success. For assisting the new well trajectory design, a small scale fracture study was carried out with focus on the southern part of the field.

The main data available for the study includes FMI image logs, DSI, mud logs, DST and open-hole logs for both wells A and B. An example of a set of interpreted potential productive fractures is shown in Figure 3. The set of fractures have large aperture observable on FMI images (track 2 in Figure 3) and strong energy losses on DSI logs (track 4 in Figure 3). They also a have high angle of dip with strike along a NNW-SSE orientation.

The interpreted potential productive fractures for both wells A and B are presented in Figure 4. The potential productive fractures mostly have high angle dip with strike either NNW-SSE or N-S. There are a few low (striking E-W) to medium angle (striking N-S) potential productive fractures observed in well B (Figure 4) as well. Another type of fracture, called continuous conductive fracture, as well as an interpreted possible fault is plotted in Figure 5.

The dominant trend for high angle fracture/fault sets in both wells is recognized as approximately NNW-SSE (striking 330-150 degrees). It is also noted that the sub-E-W set of high angle fractures was also observed in both wells as a minor set.

The drilling-induced fractures in both wells consistently strike NNW-SSE indicating the *in-situ* maximum horizontal stress orientation (Figure 4). The *in-situ* stress analysis shows that the present day maximum horizontal stress is at NNW-SSE (Figure 4) orientation. This gives positive support to the interpreted sub-N-S (including NNW-SSE and N-S) set of potential productive fractures which are likely propped open under the present day *in-situ* stresses.

A Conceptual Fracture Model

In the Cuu Long Basin, the presence of convergent (folds and thrust faults), extensional (normal faults, pinnate joints and dykes) structures with complex shear of displacement on nearly vertical surfaces evidences the dominance of strike-slip fault-related tectonics stresses (Wilcox et al., 1973; Sylvester, 1988).

The spatial distribution of the different structural elements and related natural and induced fractures over the Cuu Long Basin and the study field suggests a left lateral sense of displacement along the strike-slip fault (Figure 6). The slip direction and the bending geometry of strike slip faults influence the magnitude, development, orientation and attributes of natural fractures (Crowell, 1974).

Regional stress distribution and geomechanical studies of the Cuu Long Basin demonstrate that the maximum horizontal stress component trends NW-SE and normal to the minimum horizontal stress component, while the intermediate stress component is vertical. This configuration of the stress vectors supports the dominance of strike slip tectonics over the shape and evolution of the Cuu Long Basin (Anderson, 1951).

The consistency of natural and induced fractures orientation over thick sections of fractured basement and overlying sediments, as well as the bounding faults and the elongation of producing fields, suggest that little change has occurred in the stress distribution and configuration over the evolution of the Basin (Wan et al., 2009)

Several sets of natural fractures were recognized in the study field. They strike NW-SE, NNW-SSE, NE-SW, and ENE-WSW. The population of these fracture sets varies greatly over the field. This is because sub-surface fracture sampling is generally biased by orientations of well trajectories. Among those, the NW-SE and the NNW-SSE sets are the most dominating and are considered the synthetic sets or the Riedel shear. The NNE-SSW set is the secondary synthetic set of fractures. These sets are developed in orientations perpendicular or oblique to the field bounding faults (Wan et al., 2009). As they are aligned with the present maximum horizontal stress component in the field, they are the most prominent open fractures and hence the most productive sets.

Knowing the morphology and orientation of these fractures are very valuable in recognizing successful well trajectories. Wells drilled along the NE-SW orientation and perpendicular to the strike of these fractures intersected higher numbers of fractures and recovered substantial hydrocarbon rates when tested. However, the fracture inclinations of potential fracture sets may favor a specific well inclination over the other to ensure a certain angle for fracture intersection.

The antithetic fractures usually have limited fracture aperture and economic value (Harding, 1974, Figure 6). Bounding faults, related slivers and pinnate joints trend ENE-WSW and normal to the maximum horizontal stress orientation (N330 degrees) as designated by the induced fracture orientation. In the Cuu Long Basin, the nature of bounding faults change from one field to another as the stress magnitude and accommodation space varies. The relation between the bounding faults and the synthetic and secondary order synthetics and antithetic fractures are very well defined by numerous coastal outcrops and the field well data (Figure 7).

Well Trajectory Recommendation for the New Well D

Based on the understanding of the fracture characterization, in particular the dip and strike orientation for the potentially productive fractures from the existing two wells in the southern part of the studied field, it was recommended to use a high well deviation and NE-SW azimuth for the new well D prior to drilling. Such well trajectory allows a better chance to maximize the penetration for the identified NNW-SSE and or N-S sets of potential productive fractures in the southern part of the field.

Drilling Results of Well D

The new well D was drilled at a high deviation (about 65 degrees at well TD) with a NE azimuth (see actual well path plot in Figure 8). The new well penetrated into the basement about 700 m (MD). A highly productive oil well was achieved in DST. Post well fracture evaluation shows that a considerable number of potentially productive fractures were interpreted as presented in Figure 9. More importantly, the dominant fracture strike for the entire potentially productive fracture set is estimated at NNW-SSE (325-145 degrees), which is very close to what was predicted in the fracture study based on the existing two wells – A and B.

Conclusions

• The natural fractures in the granite basement reservoirs in Cuu Long Basin play key roles in providing needed permeability for fluid flowing as well as important storage capacity.

• It is crucial to characterize the potentially productive fracture set(s) for any given basement reservoir in the earlier stage of field exploration. This is usually hard to achieve without having at least one vertical well drilled with enough basement penetration and good quality of borehole images, sonic scanner data, plus some dynamic data such as mud logs, DST and/or PLT.

• A successful productive basement well relies on good quality seismic data to determine a well location and good quality borehole image logs to understand fracture characterization for optimizing the wellbore trajectory.

• The case study shows how important it is to have an optimal well trajectory to deliver a good well in the basement of the studied field.

• The experience learned from this case study has implications for future exploration and development drilling of basement.

Acknowledgements

The authors would like to thank Petronas Carigali and PetroVietnam for permission to use the data for this publication. We also thank those who were involved in discussions from both Petronas and Schlumberger, in particular Mr. Phuong The and Aung Than Oo who did the FMI and Sonic Scanner data processing for well D.

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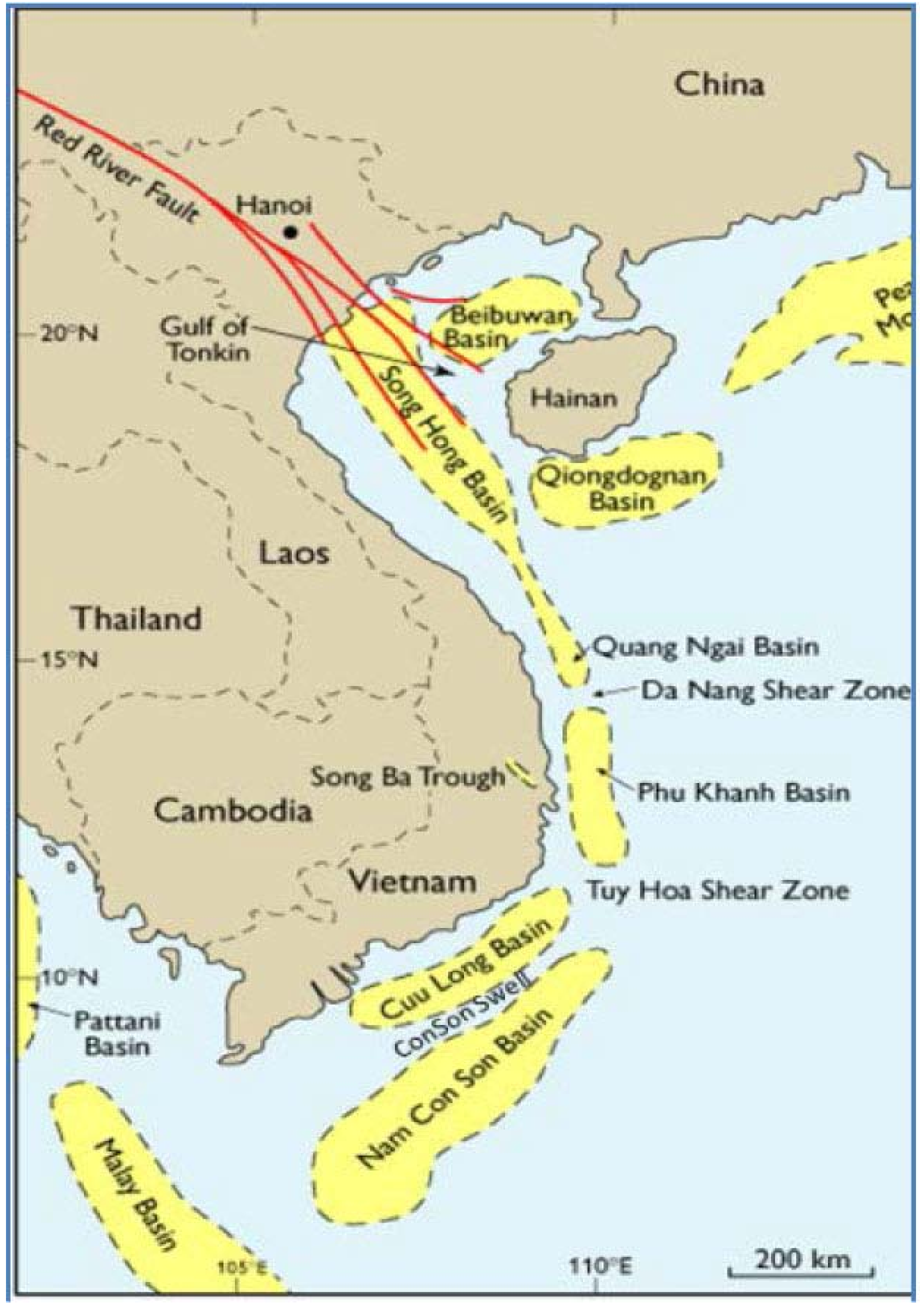

Figure1. Location map of the Cuu Long Basin.

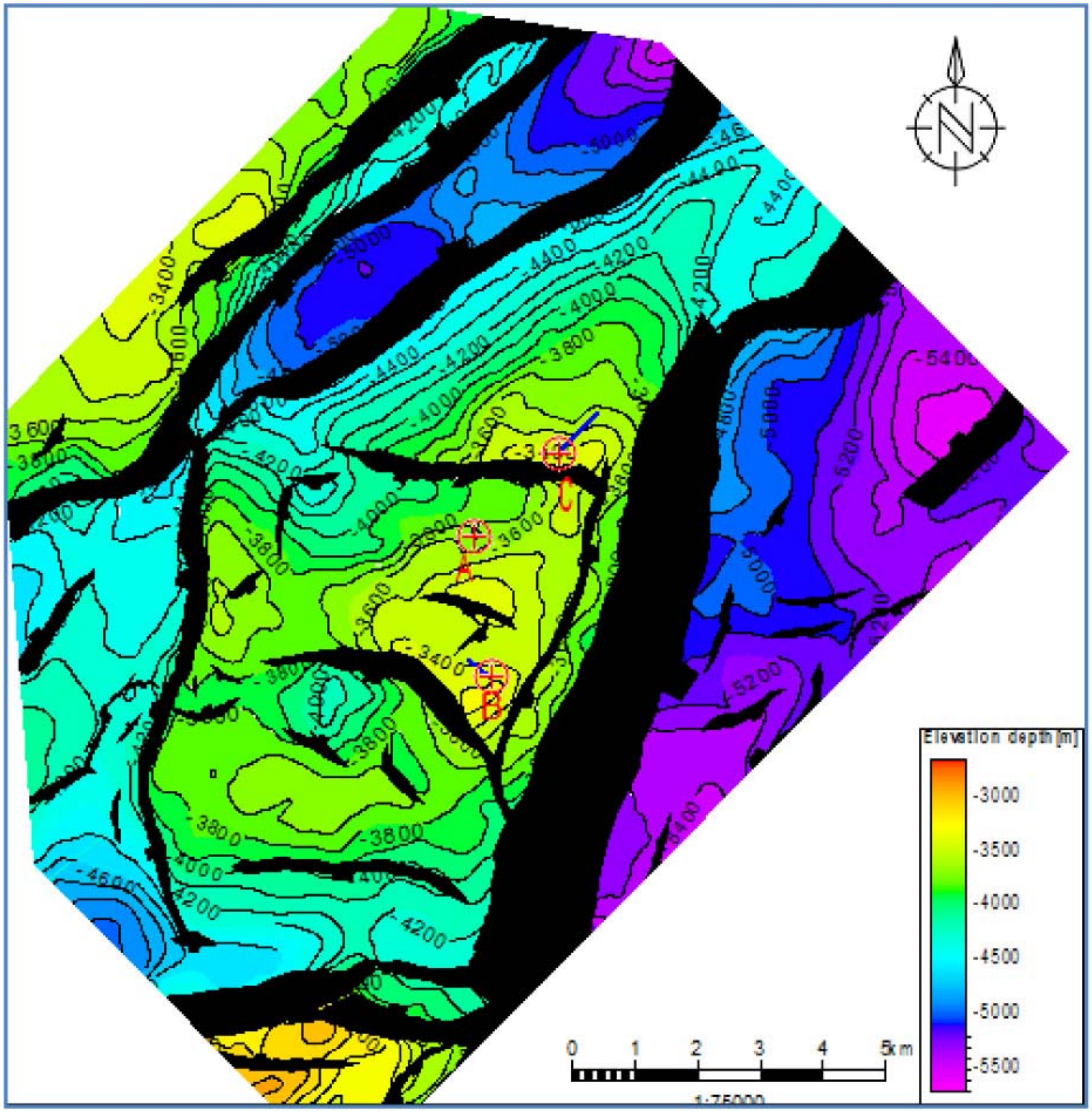

Figure 2. Top basement structural map with well locations in the studied field.

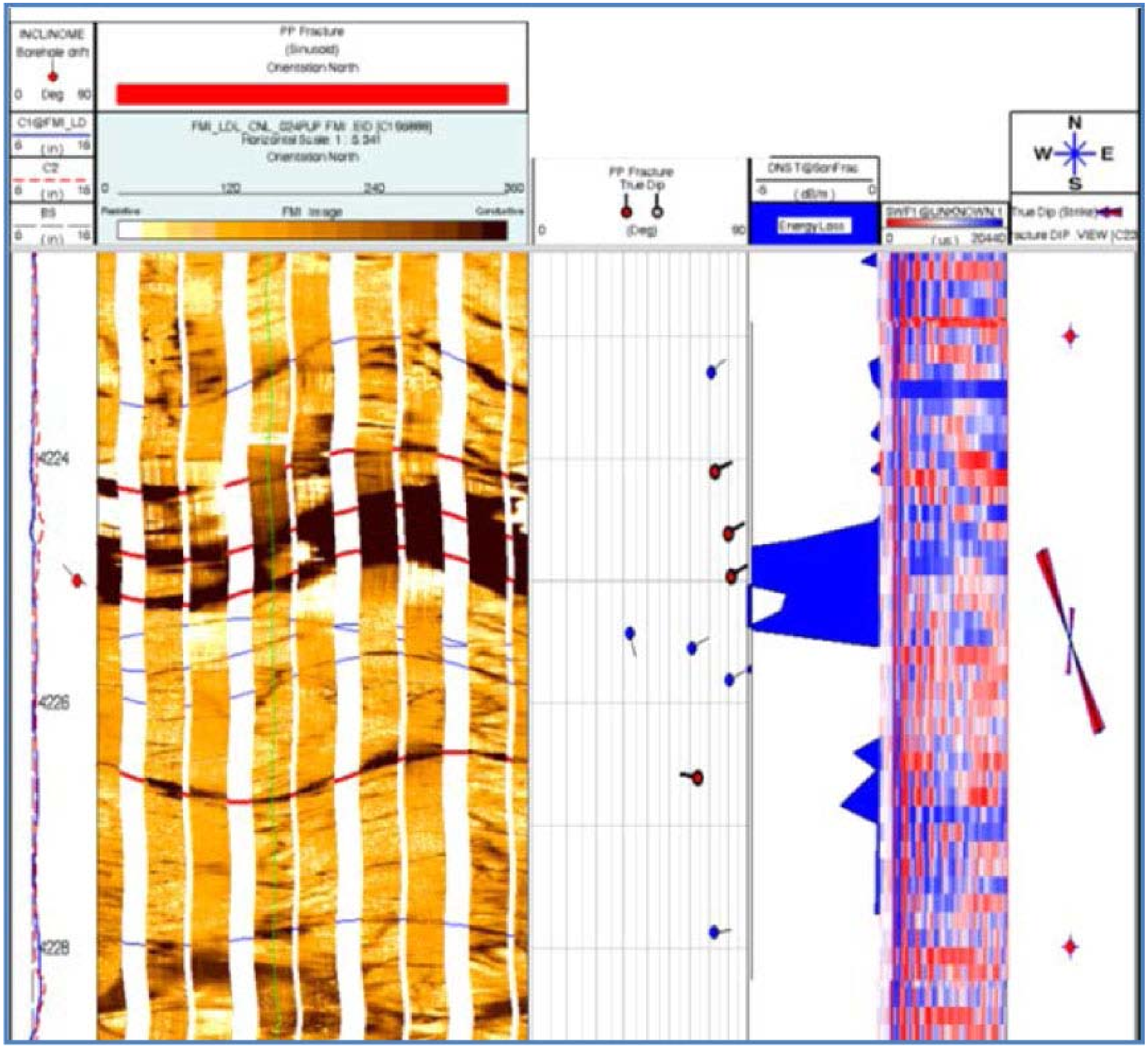

Figure 3. An example showing a set of interpreted potentially productive fractures striking NNW-SSE (see track 6) with sub-vertical dip (red tadpole in track 3). Energy losses from DSI are displayed in track 4 and DSI images in track 5.

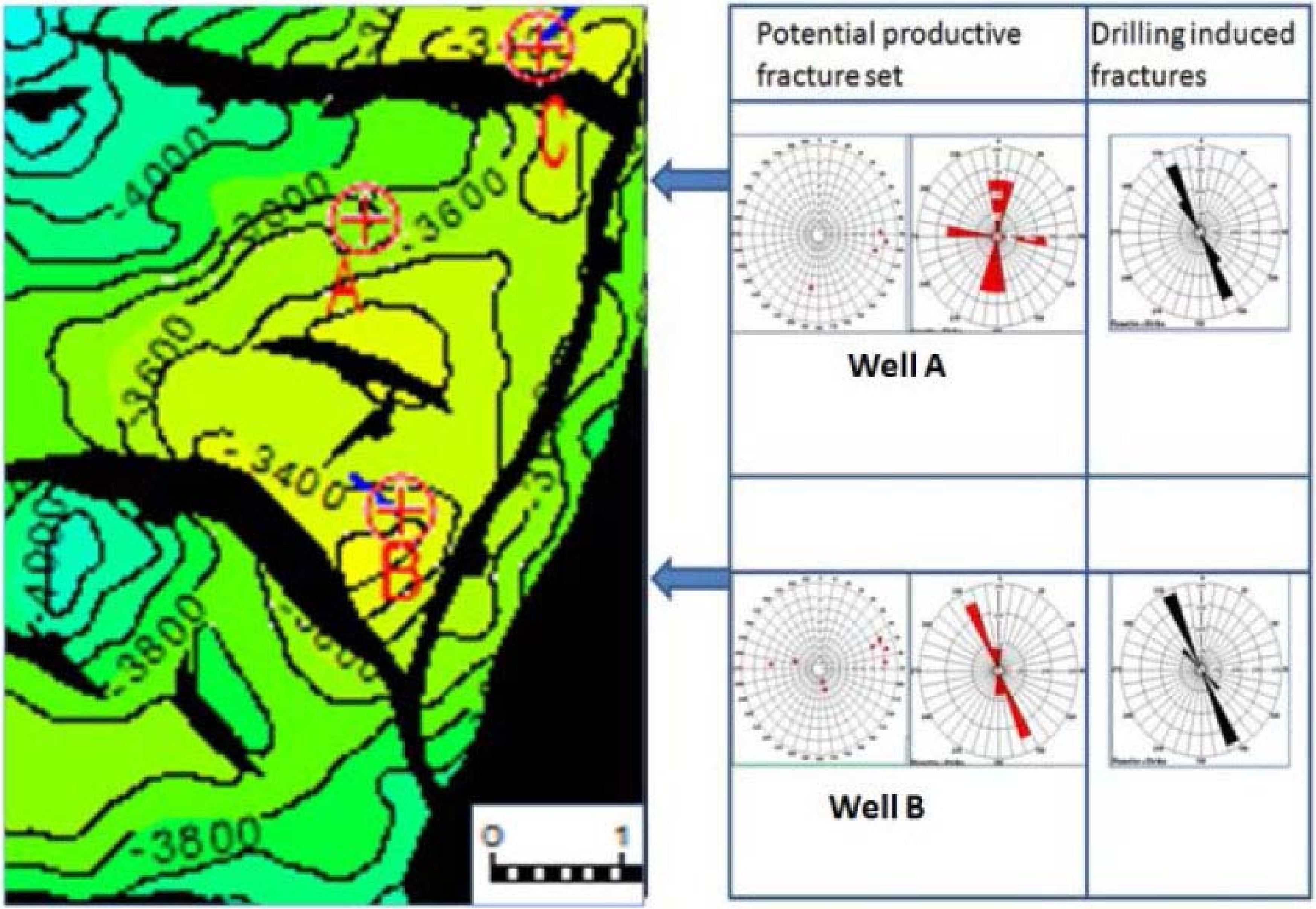

Figure 4. Summary of the interpreted potentially productive fractures as well as drilling induced fractures for both wells A and B.

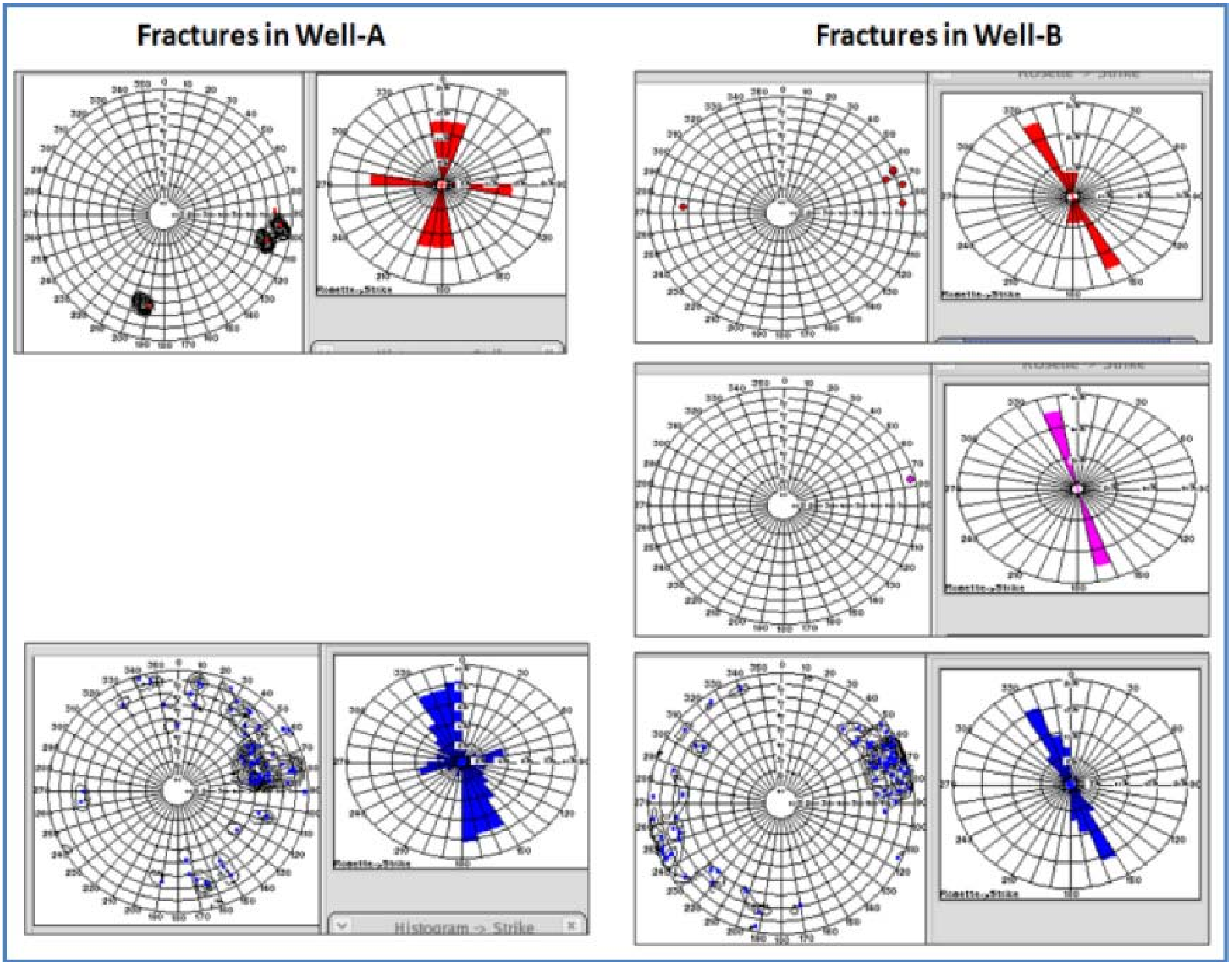

Figure 5. The interpreted fracture and fault summary for both wells A and B. Top row: dip steronet and strike plot for high angle potential productive fractures; middle row: dip stereonet and strike plot for fault, and bottom row: dip stereonet and strike plot for high angle continuous conductive fractures. Note the low angle fracture population for each type was filtered out in the plots for the purpose of studying the high angle fracture trends.

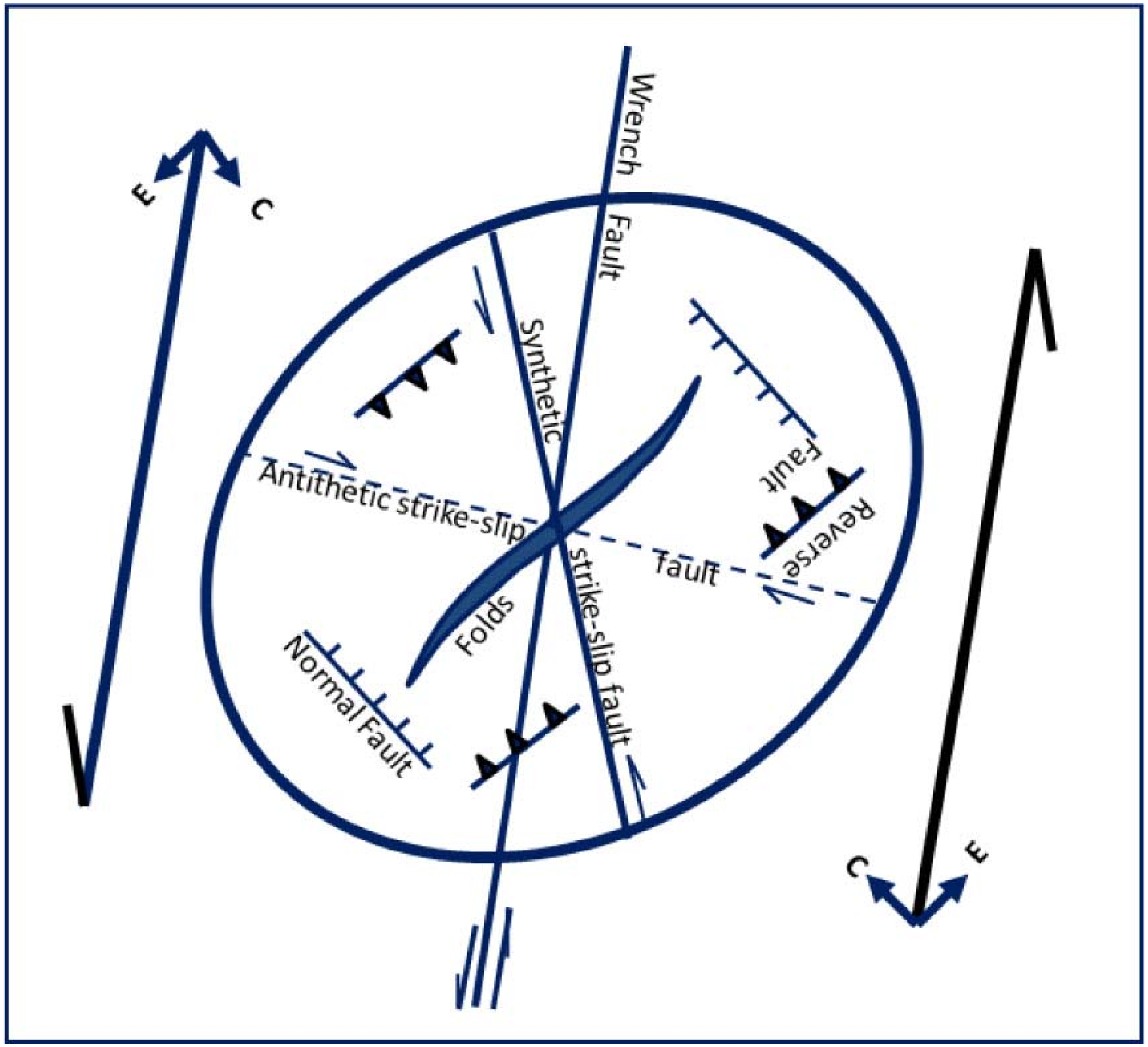

Figure 6. Geometric relation of folds, faults and shear fractures in a left-lateral strike-slip wrench setting (Taha, modified from Harding, 1974).

Figure 7. Outcrop from southern Vietnam coastal area where dykes strike NE-SW, parallel to bounding faults and normal to the N-S and NW-SE fracture orientations.

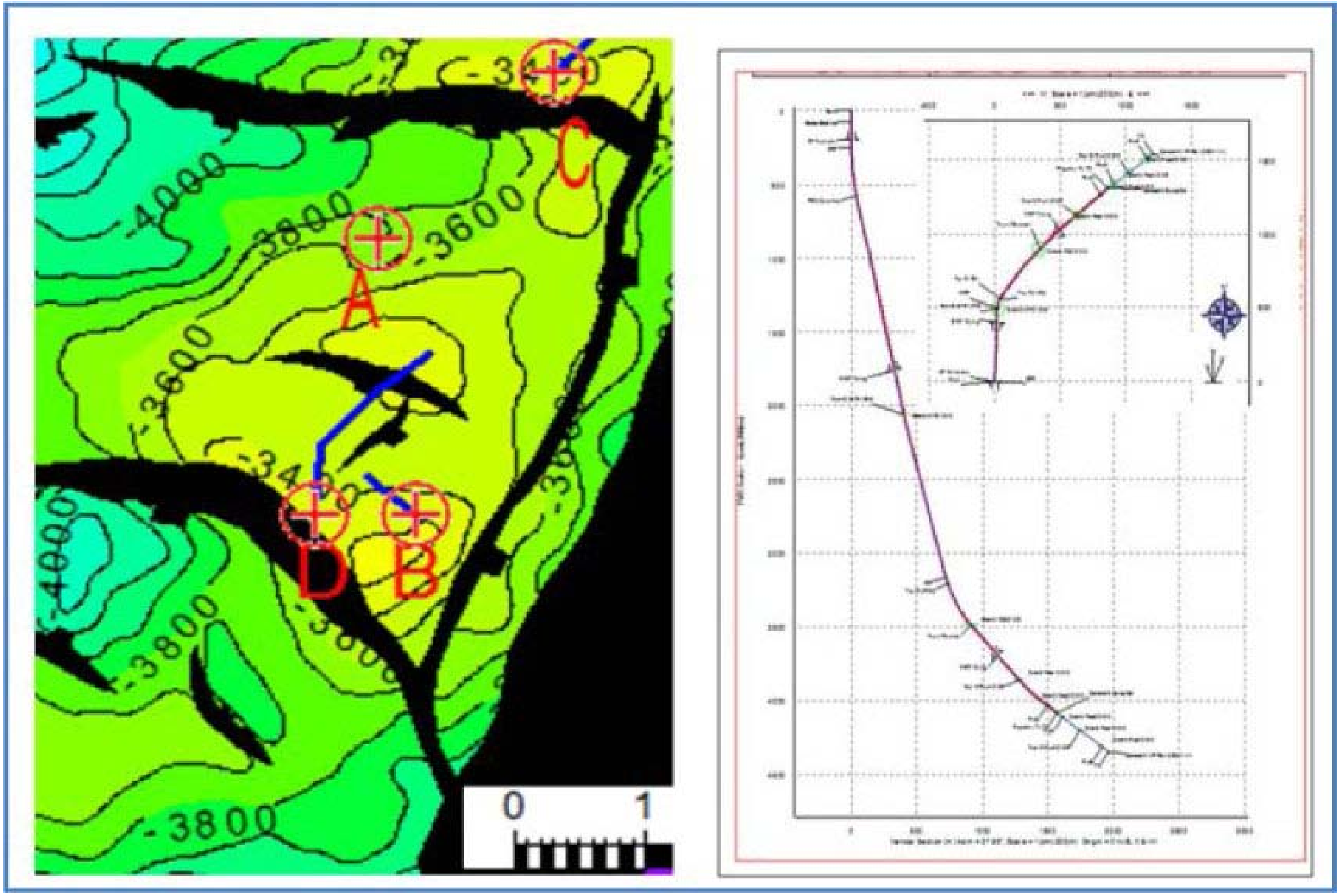

Figure 8. The well location and actual well trajectory for the new well D.

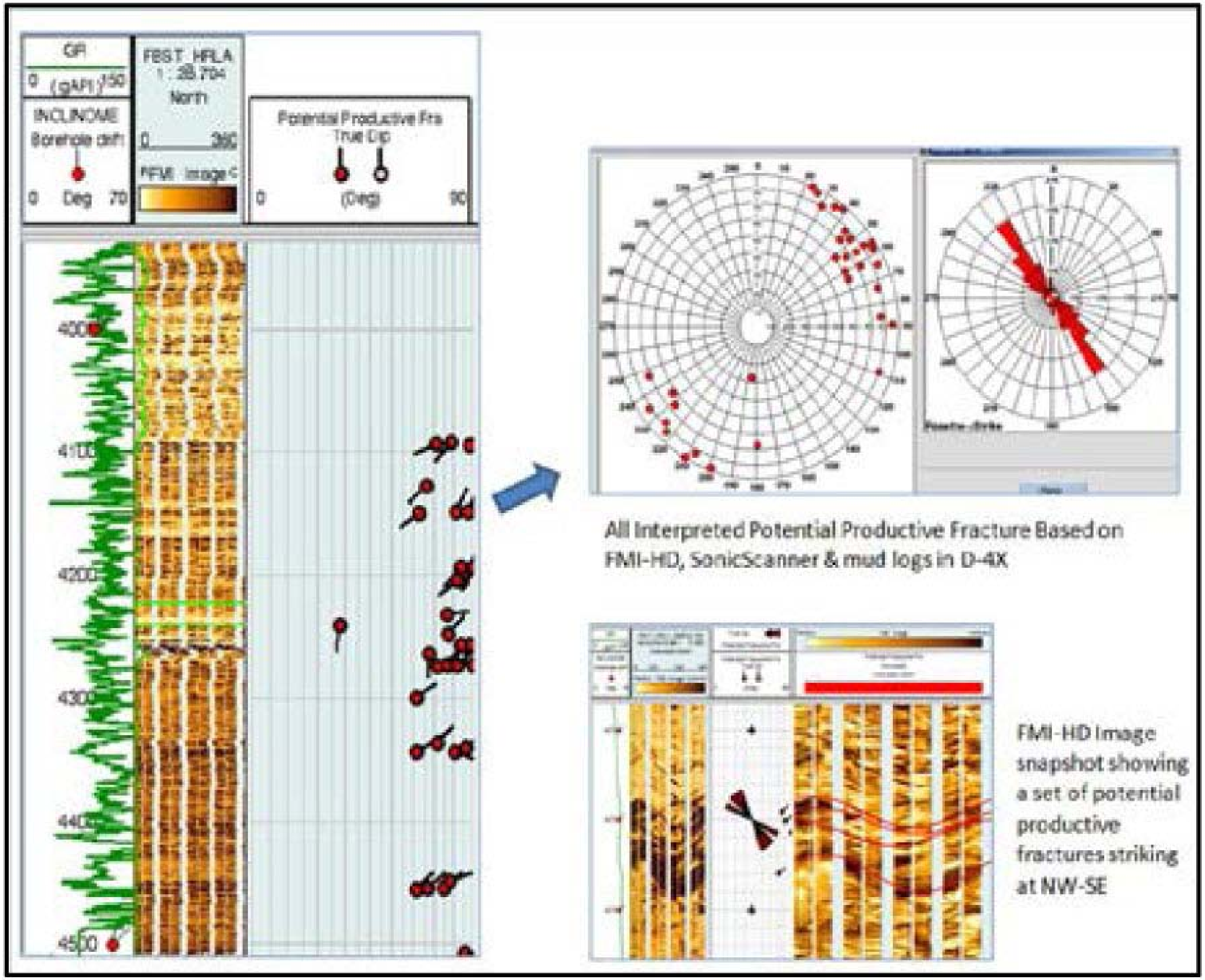

Figure 9. Summary of the interpreted potentially productive (PP) fractures in the new well D based on FMI-HD image data as well as mud logs. Left plot: depth view showing the PP fractures location in MD depth; top right: stereonet and strike plot for the PP fractures; bottom right: an image snapshot showing a set of PP fractures.