Paper ID: 2011870

Establishing the ancient and present-day geomechanical state using high-definition Structural modeling and acoustic properties

S. Shasmal[1] , K. Ghosh[1], S. Banik[1], D. Kalita[1], T. Bhattacharya[1] and E.J. Rao[2]

1- Schlumberger Asia Services Ltd., D105, TTC Industrial Estate, MIDC Nerul, Opp. D Y Patil Stadium Thane Belapur Road, Nerul EAST , Navi Mumbai – 400706

2- Oil And Natural Gas Corporation Ltd., Rajahmundry, India

Presenting author, E-mail: sshasmal@slb.com

Abstract

The Upper Cretaceous to the Lower Jurassic clastic reservoir in onshore eastern India always presents an enormous exploration challenge due to the enormous variation in tectonic events. Therefore, in such a scenario, determining reservoir geometry and geomechanical properties are essential information for a field development plan. In the present study, an attempt has been made to integrate advanced structural modeling along with rock mechanical analysis to obtain an insight into the complex tectonics.

The microresistivity image log features recognition and high-resolution dip data, allowing for data interpretation to analyze the regional trend and thus extract the subsequent structural units. Based on structural units and the dip data, the well tops were propagated in 3D space to build a subseismic geological model. The study revealed two different units in terms of geometry and ancient stress direction. Additional image-based stress analysis was performed to identify the present day stress condition. Basic petrophysical logs, in addition to the image log features, had established two different litho packages and structural units in the studied well. The high-definition structural model using dip data established the presence of angular unconformity between these two litho-packages. A detailed study of the acoustic properties has shown similar trend change across the unconformity.

Hence, this observation could lead to the identification of two different stress regimes based on tectonics in terms of rock mechanical properties and the directional sense. Abrupt variation in the stress regime in a field as was found helped in developing a precise mechanical earth model (MEM), which further helped to optimize the wellbore stability. Integration of advanced structural modeling with the help of a high-resolution resistivity image log along with rock mechanical analysis assisted in obtaining an insight into the complex tectonics in the study area. This study has helped in the future field development plan and also in the optimization of wellbore stability.

Introduction

Synrift sediments, promising hydrocarbon exploration targets, are found around the world. A synrift sedimentary sequence is encountered onshore in the Krishna-Godavari basin, which is located in Andhra Pradesh, India. One of the major challenges in the exploration of this basin is the stress condition. The synrift phase of the basin represents a complex structural and geomechanical condition. In such complex regimes, understanding of stress anisotropy and basin tectonics is essential.

An attempt has been made to establish basin tectonics and present-day stress relationship using an image log and an acoustic log. A high-resolution microresistivity image log was used to extract fine-scale dips and azimuth data. Using image-derived dip information, near-wellbore structural modeling was performed to understand the formation structure responsible for tectonics and the paleo-stress regime. The acoustic slowness values were used to compute accurate formation elastic moduli. The acquired dipole sonic data helped to understand the stress distribution and the relative rock strength for the stratigraphic section penetrated by the well. A mechanical earth model was developed that provides a categorical description of the state of stress and relative rock strength, which play a key role in obtaining insight into the complex tectonics in the studied area.

Study area

A study has been carried out in the Krishna-Godavari basin, which is located in the central part of the eastern passive continental margin of India (see Figure 1-A). The Krishna-Godavari basin comprises numerous northeast-southwest trending horst and grabens (Arya et al. 2011). Tectonically, the basin can be divided into the Krishna, West Godavari, and East Godavari sub-basins, separated by the Bapatala and Tanuku Horsts, respectively. The west Godavari sub-basin is further separated by the Kaza-Kaikalur Horst into Bantumilli and Gudivada grabens (Figure 1-B) (Arya et al. 2011). The present study is focused on the Bantumilli sub-basin. Stratigraphically, the zone of study falls into the Nandigama and Raghavapuram shale (see Figure 1-C), in which the Raghavapuram shale is underlain by the Nandigama formation.

During the Cretaceous period, the depositional environment of the Krishna-Godavari basin was mainly controlled by a series of rifting phases. The Early Cretaceous period was dominated by continental-dominated deposition, although marginal marine conditions became increasingly common towards the end of the rift phase (Barremian age). The end of rifting is marked by an erosional unconformity followed by a basin-wide flooding and blanketing of the synrift sediments by the marine Raghavapuram shale.

Data use and processing workflow

Data Sources

• <u>Fullbore Formation Microimager</u>

Real-time borehole images of the formation and dip data with 0.2-in. image resolution make microresistivity-based measurements by the fullbore formation microimager the preferred approach to visualizing sedimentary features and determining dip for structural analysis.

• <u>Dipole Shear Sonic Imager and Mechanical Earth Model</u>

The dipole shear sonic imager tool was used to acquire the subsurface acoustic information. The acquired data were processed to extract the three different slowness, rock mechanical properties along with the 2D elastic anisotropy. Using the acoustic processed result along with the density and the drilling data, a 1D mechanical earth model (MEM) was developed. The MEM model gives an explicit description of the state of stress and relative rock strength for the stratigraphic section penetrated by well.

Workflow

To achieve the objective of determining the stress relationship with tectonics along with present-day conditions, a novel workflow has been adopted for generating a high-resolution model of the reservoir and geomechanical properties using sonic data. The workflow presented in Figure 2 was adapted to a single well.

Step 1—Initially, image processing and manual dip interpretation were performed that served as the basic input for the modeling process (Figure 3-A). In the next step, filtering of the structural dips was performed to obtain the in-sequence dips and exclude the out-of-sequence dips (Figure 3-B), which were locally deformed or confined to very near the borehole. This procedure was followed by the structural dip zonation and computation (Figure 3-C). Subsequently, delineation of the structural axis was carried out (Figure 3-D) for the entire study interval. The main purpose of structural axis delineation is to decipher the various structural units and elements. The stereonet shown in Figure 3-E shows the structural axis (triangular point) and the translation plane (great circle). Based on the structural trend, the entire study interval was grouped into two major structural entities.

Afterward, identification of well tops (Figure4-A) were made with the help of the regional geological information about the area. The well tops were further used to create isopach maps for each stratigraphic zone. In the final stage, based on the principle of structural geology (Graymer et al. 2005), the well tops were projected away from the well to create a surface model (Figure 4-B). After performing the structural dip projection, the model was completed by creating the surface (Figure 4-C) and the edges (Figure 4-D) to construct the final model.

Step 2— Detailed breakout- and drilling-induced fracture (DIF) identifications were made to identify present-day stress orientation (Figure 5-A). The DIF and breakout direction revealed ENE-WSW maximum present-day stress orientation (Figure 5-B).

Step3— A special dipole mode enables recording both the inline and cross-line (perpendicular) waveforms for each dipole mode. This mode, named both cross receivers (BCR), is used for anisotropy evaluation. Shear-wave splitting and orientation of the fast shear azimuth is the key initiative for the anisotropy analysis. This analysis consists of advanced processing of the dipole sonic data and performed to develop the 1D MEM.

Results

The detailed image interpretation and dip analysis for the case study well provided a subseismic high-resolution surface model (Figure 6-A). The result reveals distinct variations within the reservoir geometry with respect to the stratigraphy. Additional analysis identified two lithostratigraphic groups separated by an unconformity (Figure 6-C). The lower unit showed a tilted block that might be the result of synclinal folding along with normal faulting.

This tectonic structure indicates an extensional stress regime where the major horizontal stress is parallel to the fold and normal faulting axis; i.e., ENE-WSW (Figure 6-C).

The anisotropy analysis result shows a strong change above and below a certain layer (Figure 7), changing the maximum horizontal stress direction. The overlying and underlying formation shows two distinct trends in the density and Young's modulus (Figure 7-A). The pore pressure also varies significantly above and below that layer (Figure 7-B). This result is most certainly an indication of some abrupt changes, and it was inferred as an unconformity plane along with the image log.

Conclusions

Integration of advanced structural modeling with the help of the high-resolution resistivity image log in addition to rock mechanical analysis assisted us in obtaining an insight into the complex tectonics of the study area. The results showed distinct variations within the reservoir geometry. A detailed image interpretation and dip analysis for the case study well provided two distinct structural units, which are further identified as two differing litho-stratigraphic groups separated by an unconformity. Delineation of the reservoir geometry from this high-resolution 3D geological model helped in identifying a folded structure uncomfortably overlain by gently dipping beds. Basic petrophysical and acoustic logs coupled with the postdrilled 1D MEM aided in establishing two distinct and different litho-packages and structural units in the case study well with different rock mechanical properties such as UCS and Young's modulus. The shear anisotropy analysis from acoustic logs revealed a change in the fast shear azimuth (parallel to the maximum horizontal stress direction) below the unconformity, which is also evident from the drilling-induced fracture direction identified in the image data. The high-definition structural model using dip data reveals the presence of angular unconformity between these two litho-packages; hence, this observation could lead to the identification of two stress regimes based on tectonics in terms of rock mechanical properties and stress direction.

Further, based on high-definition geological modeling, it has been observed that below the unconformity, there is a folded structure that was formed due to a sag effect in the extensional regime. The orientation of the structure reveals maximum horizontal stress direction toward the ENE-WSW. The same orientation is observed from the sonic stress anisotropy results, which are considered as the present-day stress condition. Hence, it can be concluded that the early and present-day stress regime below the unconformity is showing the same direction of major horizontal stress.

Image-derived dips based on structural modeling and the 1D MEM model captured the most important geo-mechanical data relevant to well construction and wellbore instability management for the remainder of the field. The postdrill 1D MEM could be used for drilling new wells around the proposed platform. This goal was achieved by determining safe and stable mud-weight windows (envelopes) at varying borehole azimuths and inclination and drill bit selection optimization.

Reference

Arya, A.K., Bhanumurty, N., and Kumar, A. 2011, Prospectivity of rift fill sequences in Krishna-Godavari basin:A case study of Kaza-Nandigama area: GEOHORIZON.

Graymer, R.W., Ponce, D.A., Jachens, R.C., Simpson, R.W., and Wentworth, C.M., 2005, Three-dimensional geologic map of the Hayward Fault, northern California: Correlation of rock units with variations in seismicity, creep rate, and fault dip; Geology, v. 33, no. 6, p. 521-524, doi: 10.1130/G21435.1, 4 p.

Zoback, Mark D., 2007, "Reservoir Geomechanics", Cambridge Univeristy Press, ISBN-978-521-77069-9, 24 p.

Reference URL source: www.dghindia.org (official site of directorate general of hydrocarbon, India)

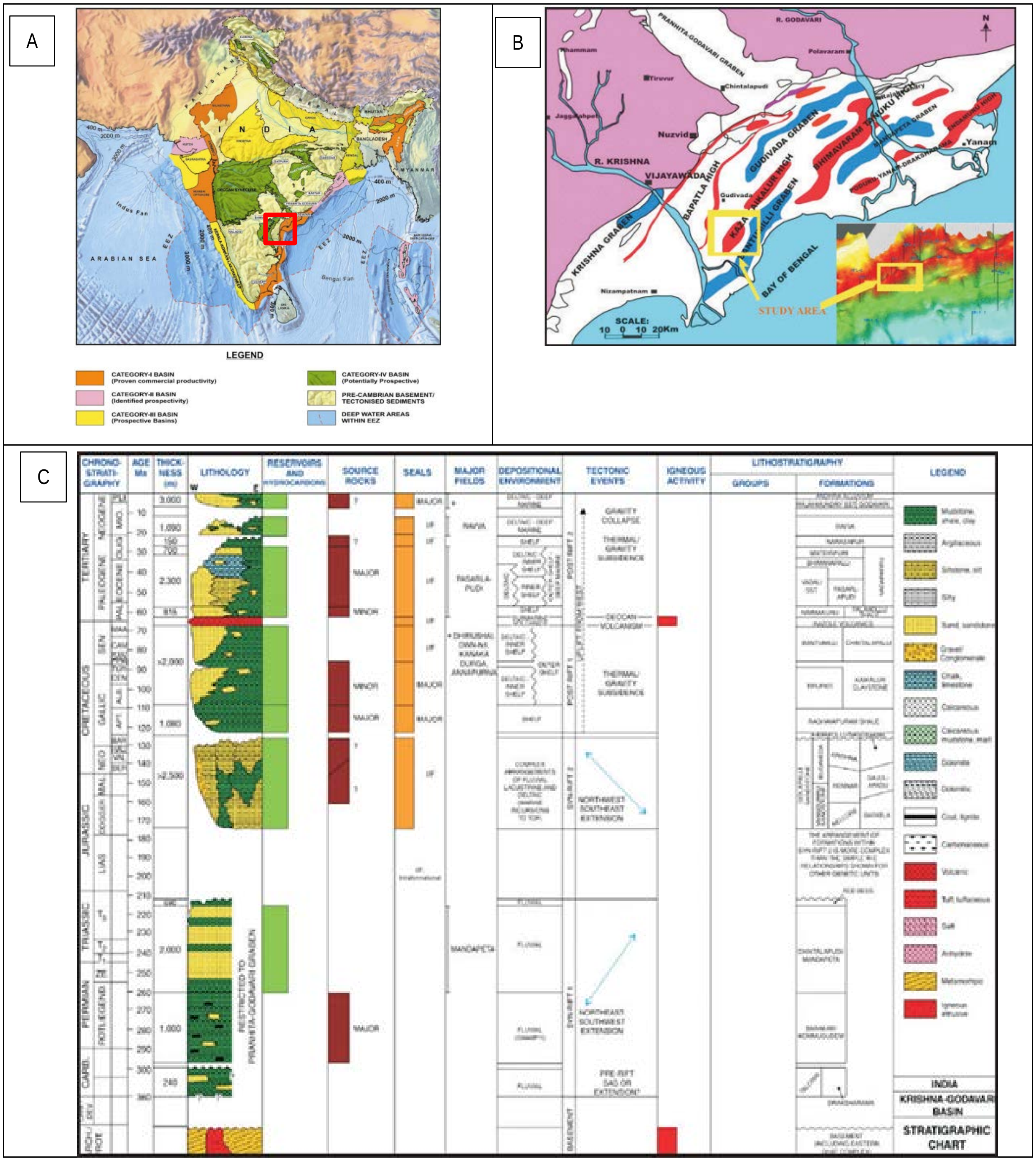

Fig. 1 Background Geological information of the field-(A)Location of the study area (source: DGH, India); (B) tectonic map of the study area; (C) generalized stratigraphy (Arya et.al 2011)

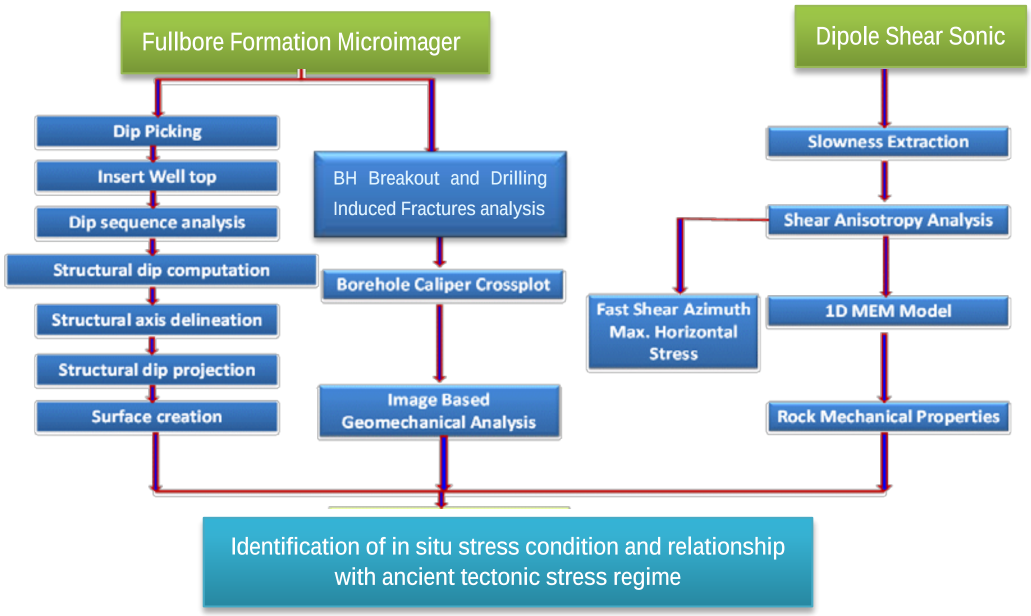

Fig. 2 Workflow of the robust methodology

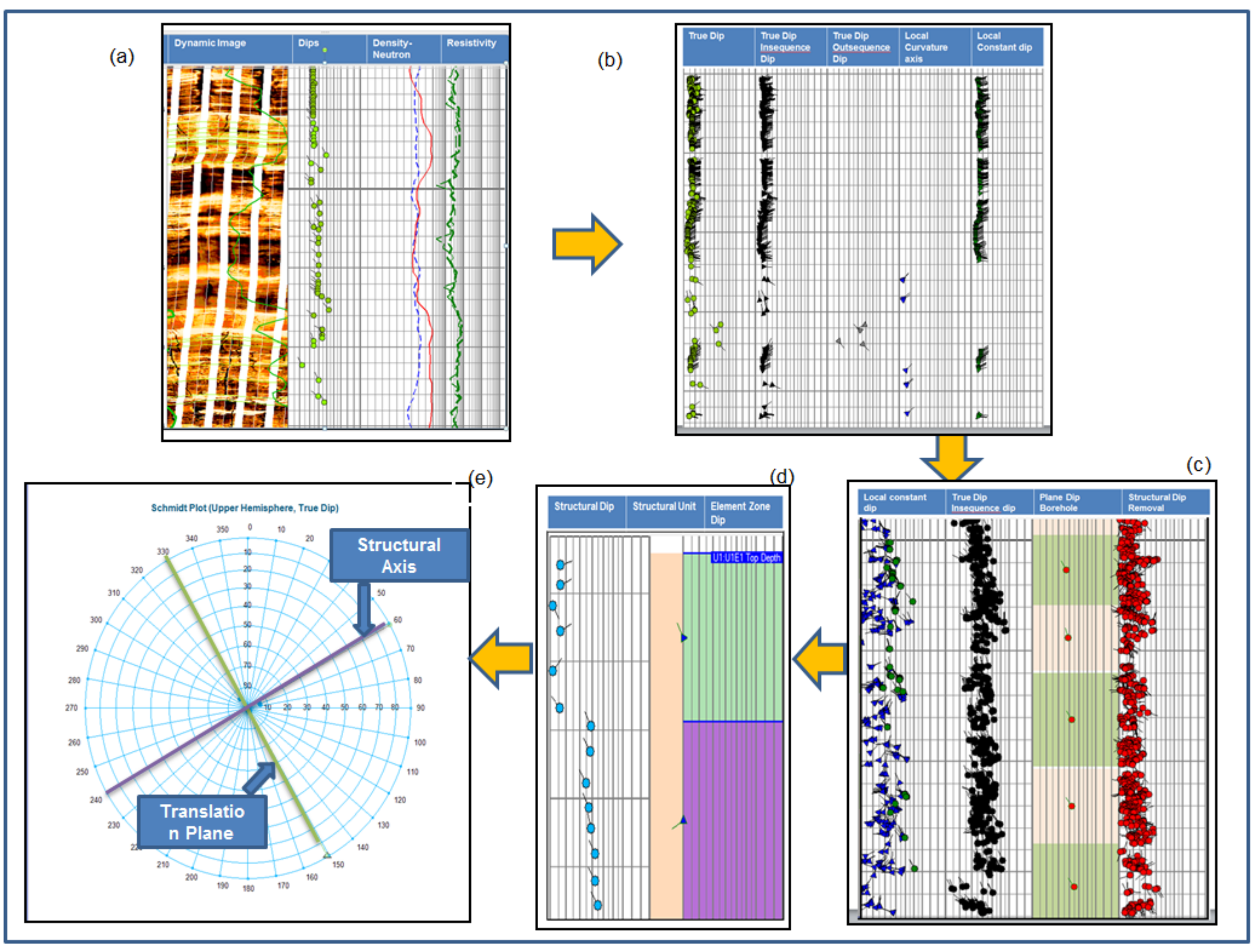

Fig. 3 Microresistivity image, dips, and conventional openhole log; (A) logical dip filtering; (B) structural zonations and dip computation; (C) structural axis delineation, unit identification, and element identification; (D) stereonet display with (E) structural axis and translation plane

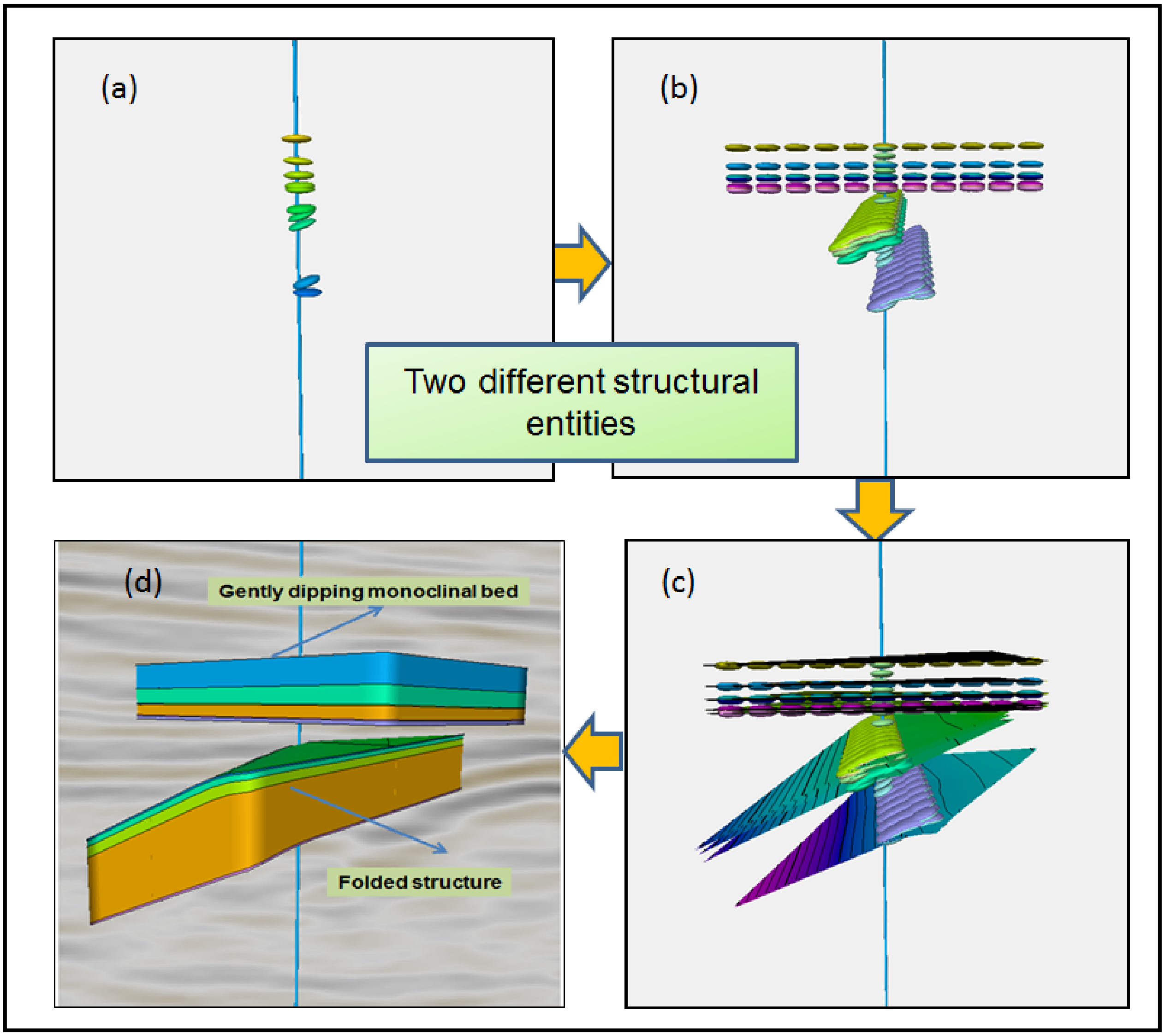

Fig. 4 Well top generation—(A); Structural dip projection in 3D display; (B) 3D surfaces created from structural modeling; (C); 3D structural model; (D) high-resolution[illegible]ntation of horizon

A

B

D

C

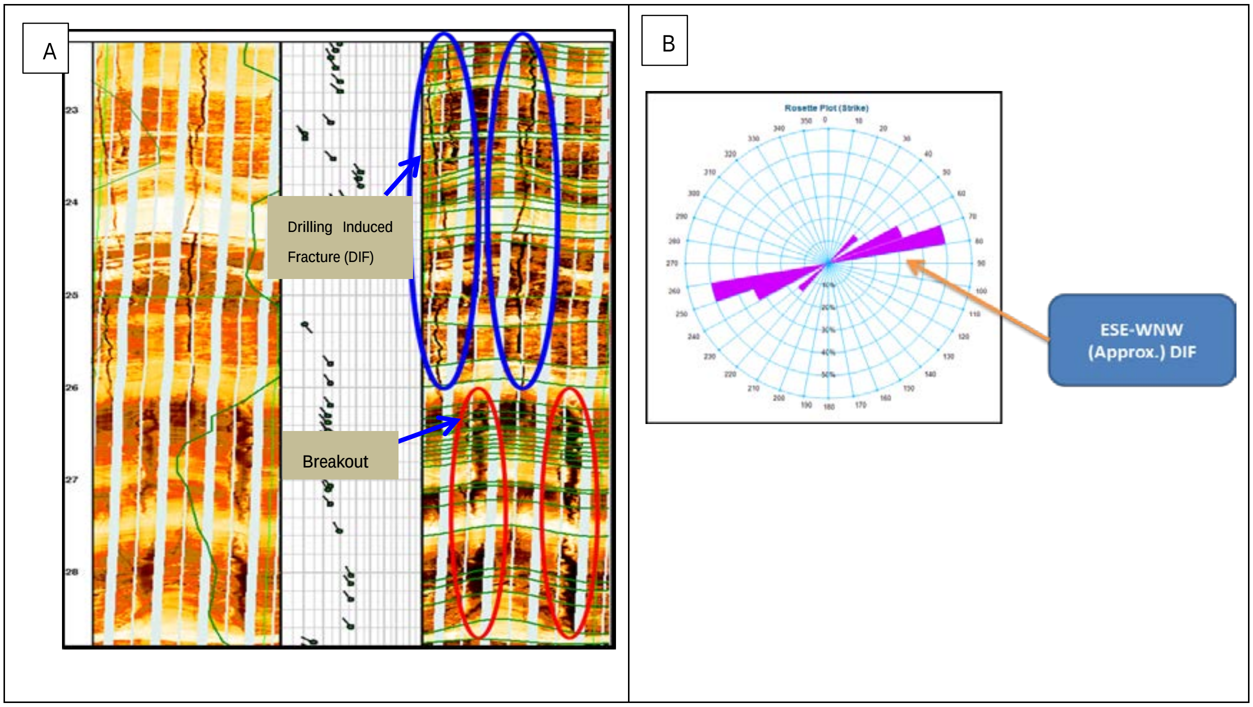

Fig. 5 Identification of breakout- and DIFs; (A) Microresistivity image log in addition to (B) strike trend breakout and DIF

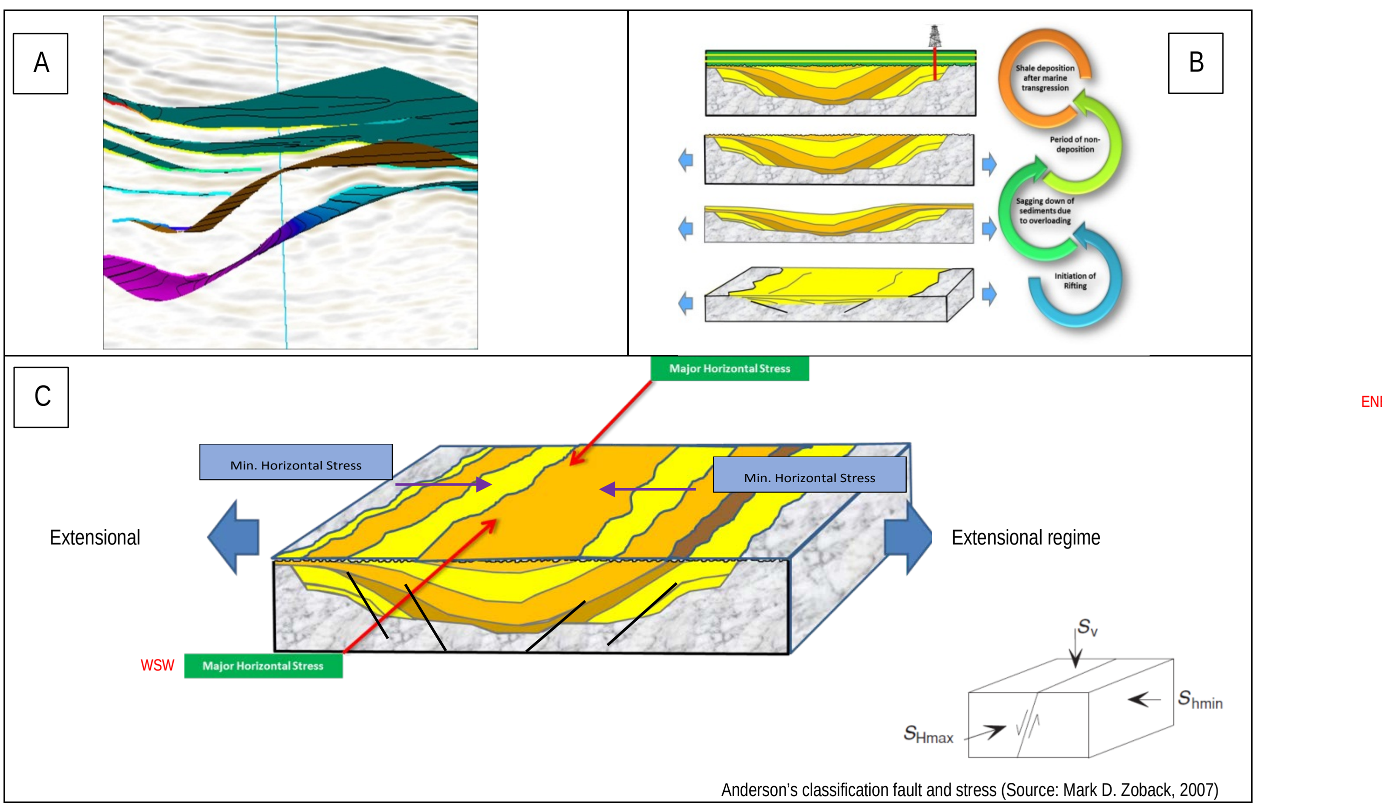

Fig. 6 Surface modeling using image-derived dips showing synclinal structure; (A) stages of basin evolution; (B) Paleo tectonic stress condition; (C) below the unconformity

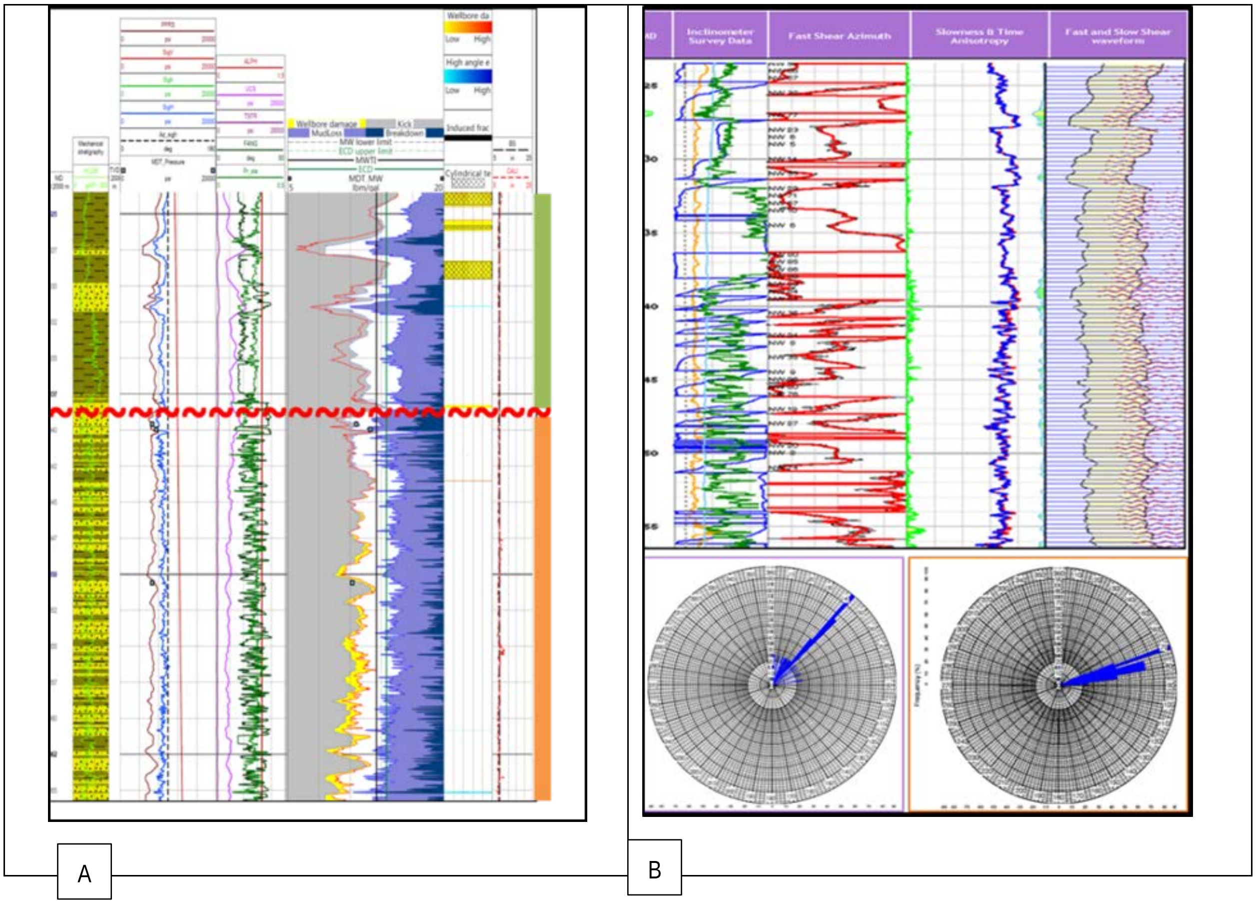

Fig. 7 (A)Postdrilliing 1D MEM; (B)and dipole shear anisotropy analysis result showing change in fast shear azimuth(max horizontal stress) across the Unconformity (UC) along with stress orientation

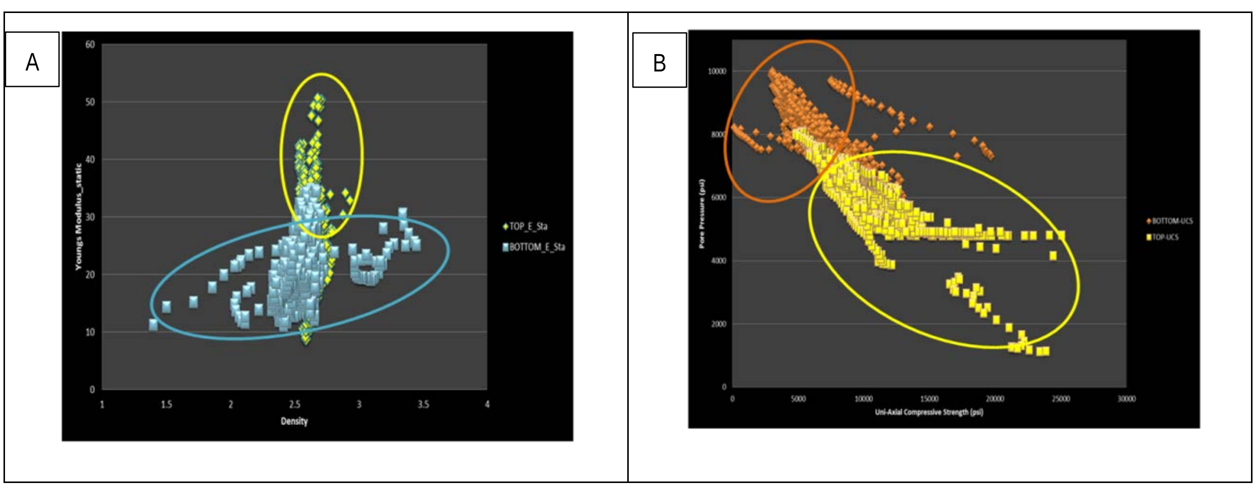

Fig. 8 (A) Crossplot showing different density and Young's modulus and (B) different UCS (Uniaxial Confined Stress) and pore pressure across the UC zone