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Predicting Fracture Distribution in Unconventional Basement Hydrocarbon Reservoir by Geomechanical Method: Case study from Borholla Field, South Assam Shelf, India.

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Abstract

Fractured basement reservoirs are challenging to model due to complex processes involved in the generation of fracture networks. In the present study, northern part of the South Assam Shelf covering Borholla field was taken up for geomechanical restoration and fracture modelling to predict discrete fracture network in Precambrian fractured granitic-gneissic basement. The basement surface was geomechanically restored at the datum and strain was calculated from unstrained geomechanically restored state to initial strained state. High strain areas were observed at the fault tips and on the both upthrown and down thrown fault blocks. Discrete Fracture Network (DFN) sets were generated in geocellular volume utilising the strain tensors as a proxy for both fracture intensity (density) and orientation, by applying geological concept models for fracture formation. Two fracture sets in NNW-SSE and E-W direction were generated by applying constraints from available well data. These two fracture sets are observed to be critically oriented with respect to the present day insitu maximum horizontal stress directionand, they are expected to have major influence on hydrocarbon production in Borholla field. The predicted DFN model after calibration and validation with well data and history matching with production data can be utilized for future field development programme and expanding the exploration targets in the adjoining areas.

Introduction

Naturally fractured granitic basement reservoir in Borholla field in South Assam Shelf (Fig.1) has been under production and development for many years. As in all other fractured basement reservoirs in world, in Borholla field also the fractured reservoirs are more difficult and expensive to evaluate than the more conventional reservoirs. It is necessary to have an early assessment of natural fracture network as it is of key importance in development of reservoirs where complete porosity and permeality is controlled by them.In this scenario a need for a robust predictive fracture network modelling technique becomes imperative to model this reservoir to increase the production by planning well locations, appropriate well designing and mitigating the exploration risk in adjoining areas.Now a days, different techniques of DFN modelling routinely involve deterministic, stochastic and predictive methods. In predictive methods, strain captured during kinematic (Sanders et al., 2004) or geomechanicalrestoration (Maerten and Maerten,2006) are used as input to predict high fracture intensity areas in the reservoir.In the present study a novel methodology is used to predict Discrete Fracture Network (DFN) based on the geological understanding of the relationship between fracture network and geological history, particularly structural history.

Geology of the study area

In Borholla area, granitic - gneissic complex constitutes the basement for sedimentary sequences of Tertiary age. The sedimentation started in Paleocene and continued till recent with unconformity during Oligocene and Mio-Pliocene. The general stratigraphy of Borholla is given in Fig-2. In regional tectonic set up the Borholla field is part of Upper Assam foreland of Assam-Arakan basin. The Naga Schuppen belt lies in the east and the surface trace of outer Naga thrust constitutes the eastern Boundary of the Borholla field. In the study area Basement is gently dipping towards southeast and it is dissected by several NE-SW trending Basement involved longitudinal normal/reverse faultshading both towards southeast and south west. Many transverse normal faults trending in approximately in E-W direction are also present. These fault systems divide the field in different local horst and grabens. The figure 3shows the representative geological cross section from the northern part of the study area. As far as tectonic evolution of the area is considered, two major episodes of tectonic deformation occurred during Tertiary period. An NW-SE extensional regime started during Early Tertiary, resulting in the formation of NE-SW oriented normal faults within the basement (Fig,7).This extensional phase was active during the deposition of Sylhet/Kopili and continued till the deposition of Tipam group. Recently 2D structural restoration of foreland part of the study areas has found maximum extension during Kopilli with minor extensions in Barail and Tipam (Singh et at.,2011). The deposition during this stage was controlled by slow subsiding hanging walls of the active normal faults. Thereafter, the areahas remained under intense compression starting during deposition of Namsang sediments of Pliocene age to Present.

Hydrocarbon Occurrence

Predominantly hydrocarbon accumulation in the field is present in fractured and weathered basement. The top 30-40 m of Precambrian granitic gneissic Basement is main reservoir zone. In addition to this, overlying Basal sandstone of Paleocene is also contributing to the hydrocarbon production from the field. The entrapment mechanism of hydrocarbons is generally envisaged to be fault closures and the upthrown fault blocks, with structurally favourable position, are more prolific producers.Besides this, some wells from structurally lower areas have given good daily production rates with moderate cumulative production (*Fig.4*).The frequency distribution of cumulative production of wells in the field shows that most of the wells are moderate to poor producers with only few wells have very high cumulative productions. Hence, the frequency plot shows a highly skewed graph towards low cumulative production. This is a characteristic feature of the entire fractured reservoirs worldwide. So, based on this type production behaviour also the Borholla field can be classified as fractured reservoir.

Natural Fractures

Natural fracture systems have profound impact on reservoir performance as they can act as highly permeable flow conduits or act as baffles and seals. So an understanding of their genesis and distribution at reservoir level is much sought after information. Natural fractures in the granitic-gnessic rock could be of three types;*primary fractures* whose origin is related to emplacement or cooling of magma, *secondary fractures* related to tectonic deformation and *fractures related to exhumation*. Generation of secondary natural tensile and shear fractures in rocks is directly related to the deformational evolution of the study areas. In Andersonianstress regime, tensile fractures are always perpendicular to the least principal stress and the shear fractures always develop as conjugate sets that are oriented parallel to intermediate stress axes and are generally 22-30^0 from maximum stress axes (Fig. 5). It has been observed that rocks with predominantly shear fractures have high porosity and connectivity as they have greater length, wider damage zone, and frequently occurring sub seismic faults. The core studies and borehole images from some of the studied wells from Borholla field show presence of fractures in variable orientations (JRC - Schlumberger Report, 1993) but are concentrated in NNW-SSE, NE-SW and E-W direction (Fig.6.). The origin of these fracture setsare intimately related to the different deformation stages of the area.The NE-SWfracture sets are associated with NW-SE oriented extensional regimein Early Tertiary whereas NNW-SSE and EW fracture sets are associated with the NW-SE compressive regime since Late Miocene–Pliocene and formed essentially during the progressive arrival of the thrust front (Price and Cosgrove,1990).

GeomechanicalRestration and Fracture Modelling Methodology

Prior interpreted basement top and faults in 3D seismic datawere imported in ASCII format in *Move*. The imported surface was resampled and smoothened. Surface Dip analysis was carried out for basement surface and zones with anomalously high surface dips representing fault zones were identified at basement level (Fig,7). These zones of high dip values match quite well with seismically interpreted faults at the basement,and are interpreted as fault gap zones. These fault zone gaps were removed prior to restoration.The basement surface was geomechanically restored at the datum by inbuilt geomechanical modelling tool kit provided in the software (Fig.8).The geomechanical restoration uses mass spring algorithm which is an iterative numerical technique designed to minimise the strain within a solid body while attempting to retain its original shape. The original purely geometric surface data structure is replaced by a mass-spring data structure that comprises a net of lumped mass points and effectively one-dimensional springs connecting these lumped masses.A mass-spring simulation proceeds by solving the force-displacement relationship over very small time intervals until the energy in the system reaches equilibrium. Constraint in the form of fault gap closure was enforced at this time.After mass-spring restoration, the change of area of original surface polygons, full strain analysis based on prescribed material properties, and displacement vectors of the original surface polygon vertices is carried out.

Basement surface was geomechanically restored to datum and the strain was calculated from unstrained geomechanically restored state to initial strained state. Strain attributes viz. dilation, strain ratio, tensors and principal strain directions were calculated.High strain areas were observed at the fault tips and on the both upthrown and downthrown side of the fault blocks (Fig.9). The principal strain axes e1, e2 and e3 vary accordingto the fault orientations.

Fracture modelling module wasused to generate Discrete Fracture Networkby utilising the strain tensors as a proxy for both fracture intensity (density) and orientation, by applying geological concept models for fracture formation.

Results and Discussion

Two fracture model scenarios were built; one random model controlled by strain attribute map derived from restorationand another scenario by interactively constraining various fracture parameters (Fig.11). In the constrained model parameters like fracture intensity, orientation, aspect ratio and aperture were specified in the fracture modelling module for prediction and generation of fracture sets in addition to the strain map which was used for controlling the fracture intensity areas. These fracture parameters were obtained from few of the wells drilled in the Borholla field from core data and FMI as discussed earlier.One of the important results of the present study is the fractures are modelled on the both the footwall and hanging wall. Origin of high intensity of fractures on the hanging wall block has been explained by Sanders (2003) due to more deformation of hanging wall block during kinematic and flexural uplift processes.

A geocellular volume with fracture sets in NNW-SSE and E-W direction were generated in 100m grid size (Fig.10). The fracture sets are concentrated in the areas of high strain viz. fault tips and along the faults in upthrown side of the fault block.The predicted fracture sets are analysed for their opening or closing mode tendency in present day regime. Several studies by other workers it has been inferred that in the present study area a compressive stressregime is prevailing and the borehole break out studies suggest that in situ maximum horizontal stress direction is oriented SE-NW (Goud, 1992). Predominantly the modelled fracturesare oriented in NNW-SSE and E-W direction and are subparallel to the insitu present day maximum horizontal stress direction, so they are expected to be in the dilatational opening mode in the present day (Fig.11). These preferably oriented fractures are expected to contribute in secondary porosity as well as to the permeability of the basement reservoir for better hydrocarbon accumulation and production.

The predicted DFN in the present workflow would be required to be calibrated with fractures interpreted from seismic attribute analysis in the form of coherency analysis and ant tracking and validated in areas with well data viz, image log, core data and production data. The geocellularDiscreteFracture Network model generated here can be exported for reservoir simulation comparison with production data and well test data and history matched for further fine tuning of the model.In this way, once the model is validated, it can be applied for future field development programme and expanding the exploration in the adjoining areas by considering the areas of high strain (the high fracture intensity)as guides to highly fractured basement sweet spots.

Conclusion

In the present study Discrete fracture network prediction is carried out for Precambrian basement reservoir by geomechanical restoration fracture modelling technique. Strain was calculated from unstrained geomechanically restored state to initial strained state and Discrete Fracture Network was generated by utilising the strain tensors as a proxy for both fracture intensity (density) and orientation, by applying geological concept models for fracture formation. Both random and constrained scenarios were run for creating DFNs. The fracture sets oriented in NNW-SSE are expected to be main contributor to hydrocarbon accumulation and production as they are critically oriented in present day stress regime to be in active mode of slip and dilation. Once the DFN model is calibrated and validated by well data and production history, the workflow adopted in this study can be used for fracture prediction in areas of poor or sparse seismic data for field development and exploring basement sweet spots in new areas.

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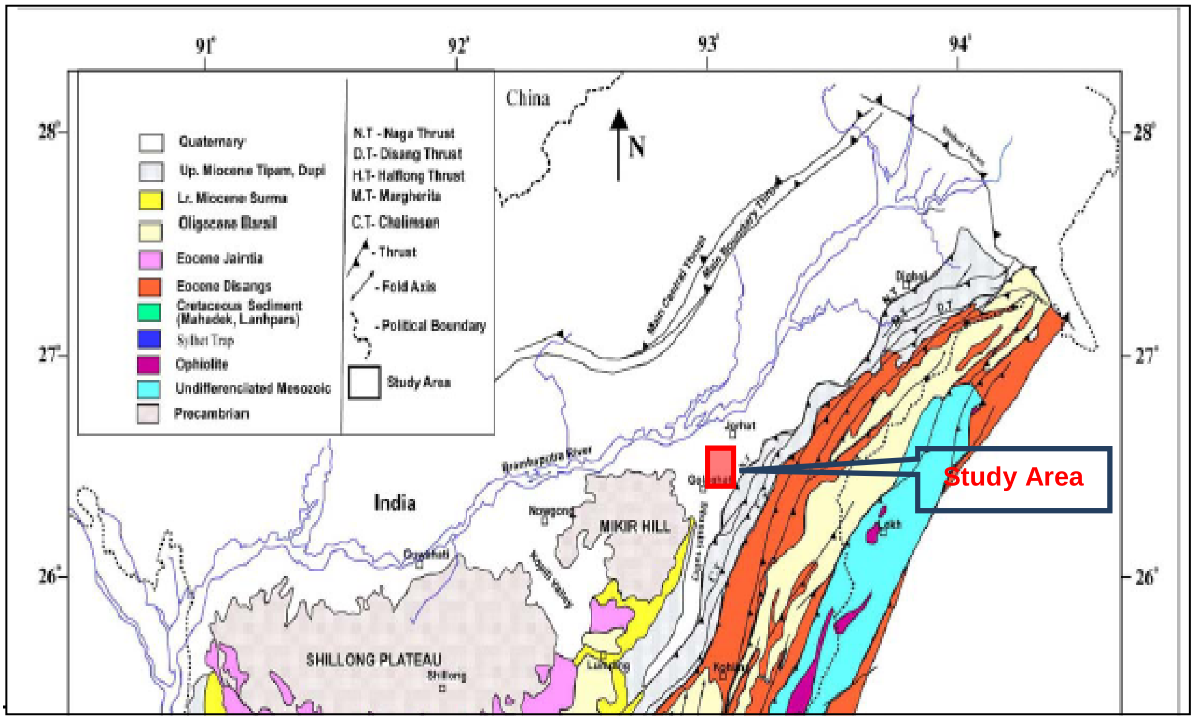


Fig1.

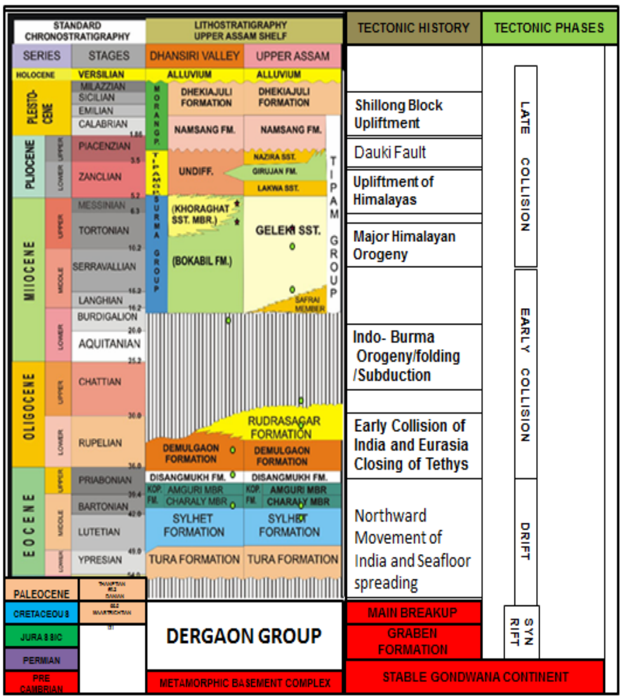


Fig.2.: Generalised stratigraphy of Assam Shelf showing different tectonic stages (after Deshmukh etal.,1993).

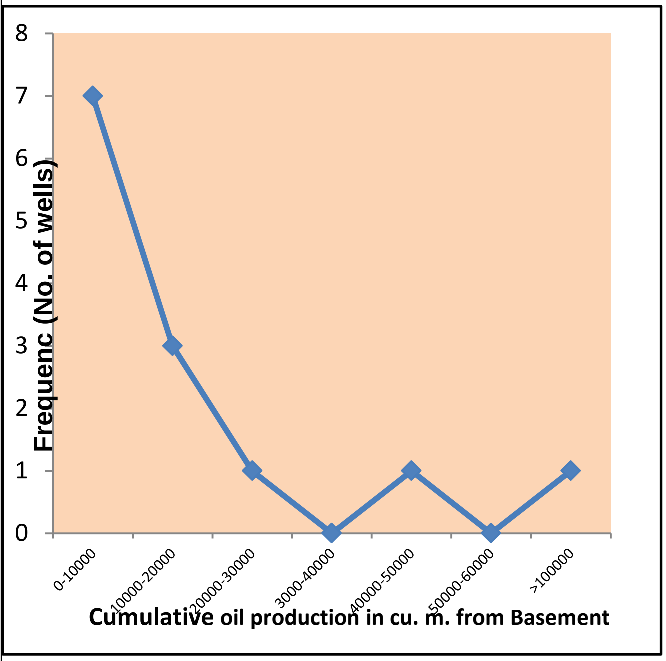


Fig.4.: HC distribution in Borholla field showing skewed distribution pattern towards lower cum. Production wells.

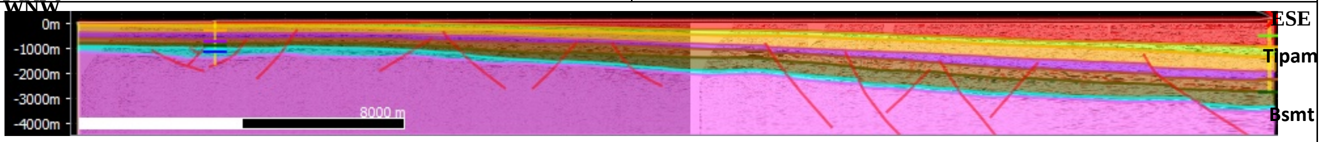


Fig.3: WNW-ESE oriented regional geological cross section of the shelf part of the study area through Borholla field.

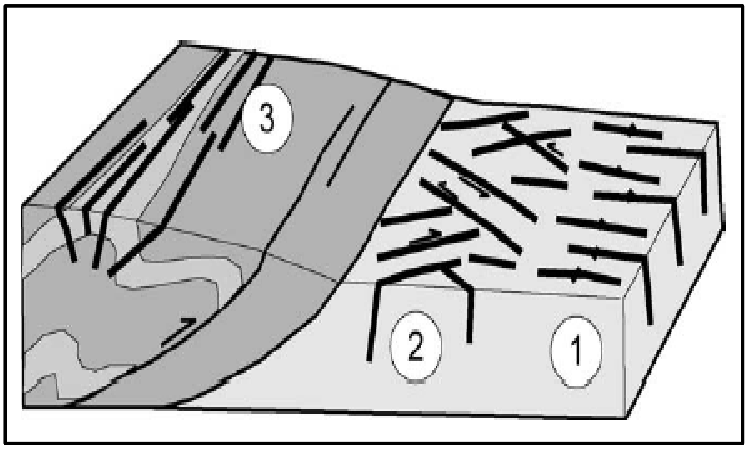


Fig.5.:Concept described by Price and Cosgrove (1990) for fracture formation in front of a thrust front. Formation of subsequently joint sets (1) and strike slip shear fractures (2) with the advancement of the thrust front. Note that the region is essentially undeformed at the time of the fracture generation. During thrusting fracture set 3 is formed.

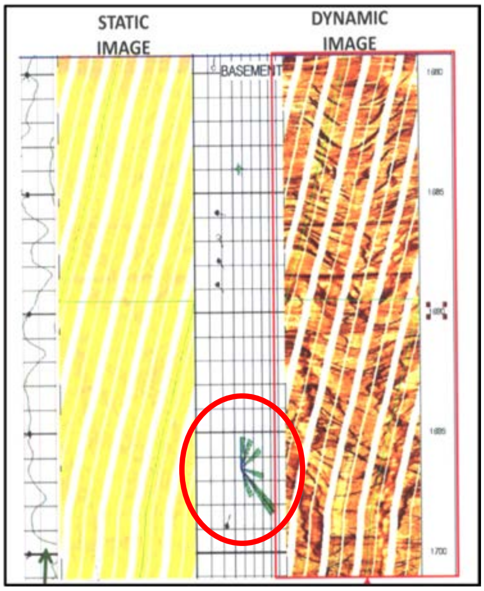


Fig.6.:FMI log in basement from Borholla area showing NNW-SSE and NE-SW oriented fractures.

Fig.7.:Basementsurface showing dip values. Warmer colour show high dip values. Seismically interpreted Fault polygons are overlaid basement surface and fit quite well to the high dip value

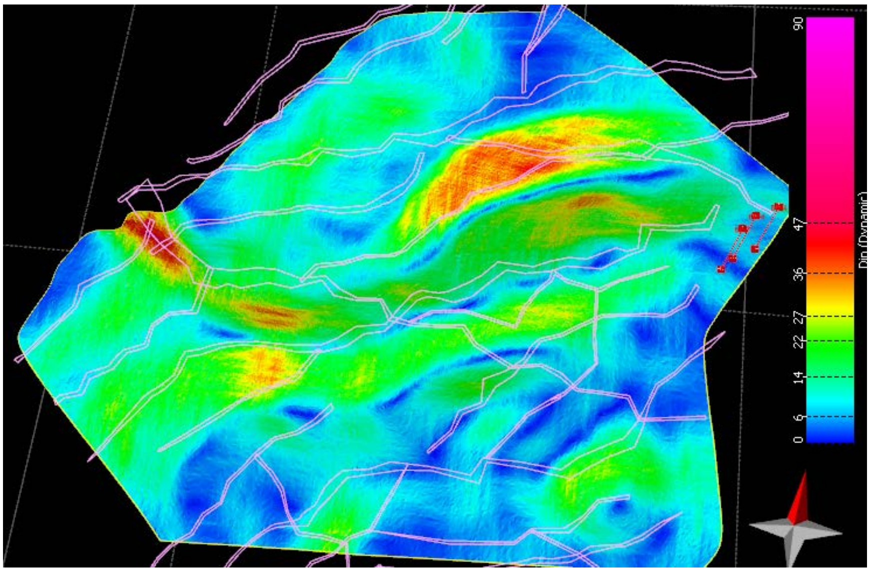
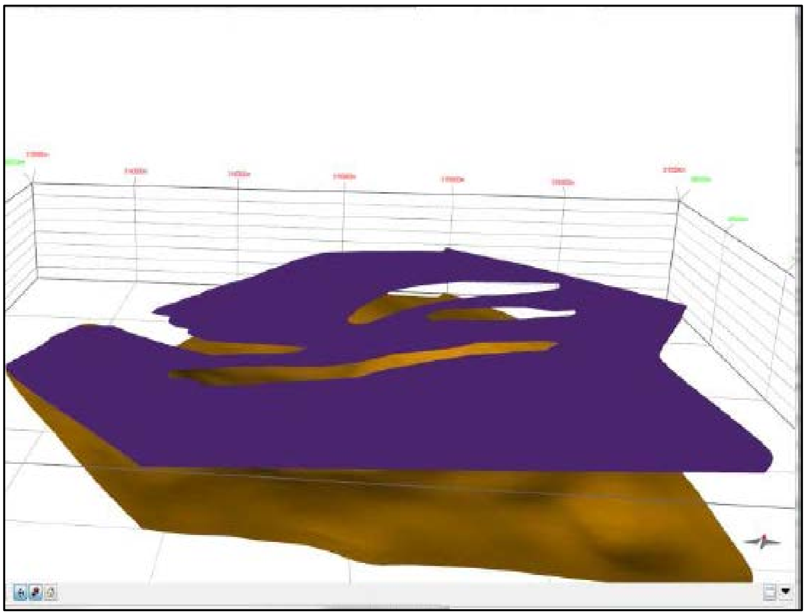
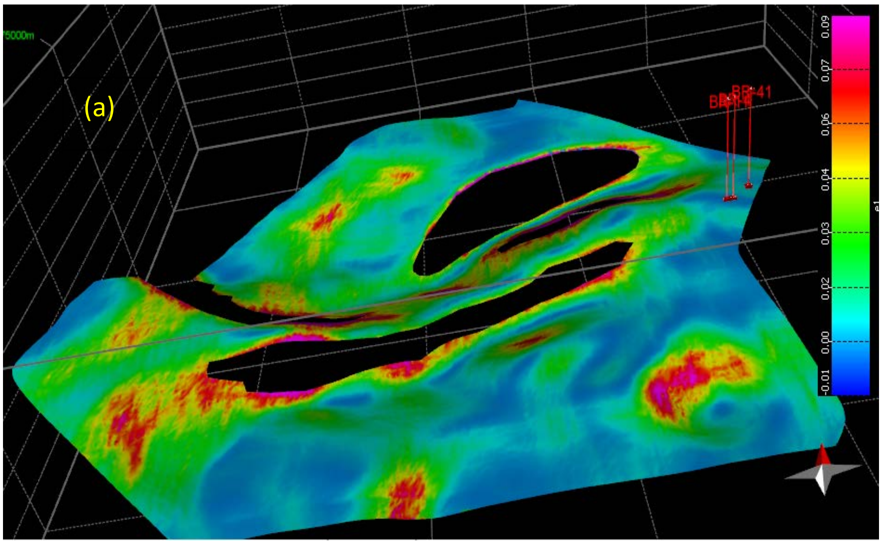


Fig.8 .: Basement surface is geomechanically restored at 1000m datum. The restored surface is flattened by restoration and shown in purple.





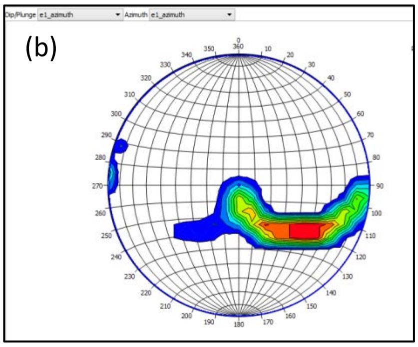


Fig.9: (a) Map showing e1 distribution pattern at basement obtained from geomechnical restoration. High strain values are in warmer colour

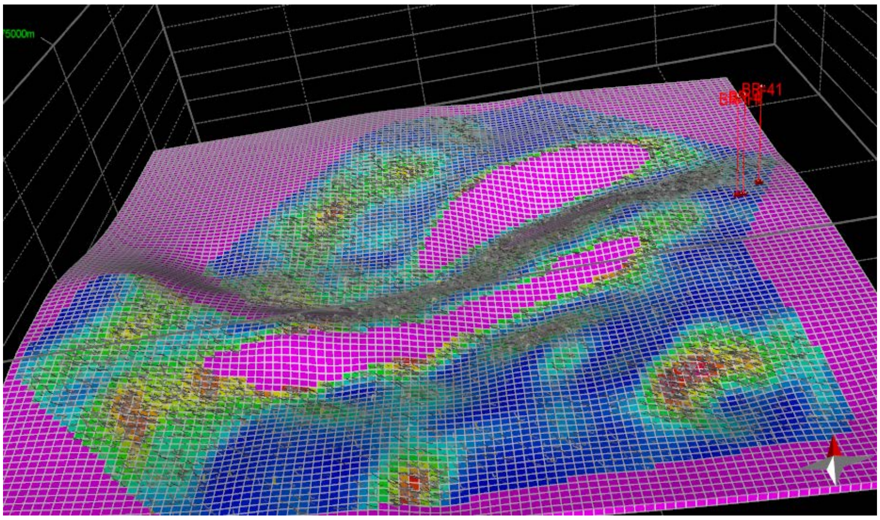
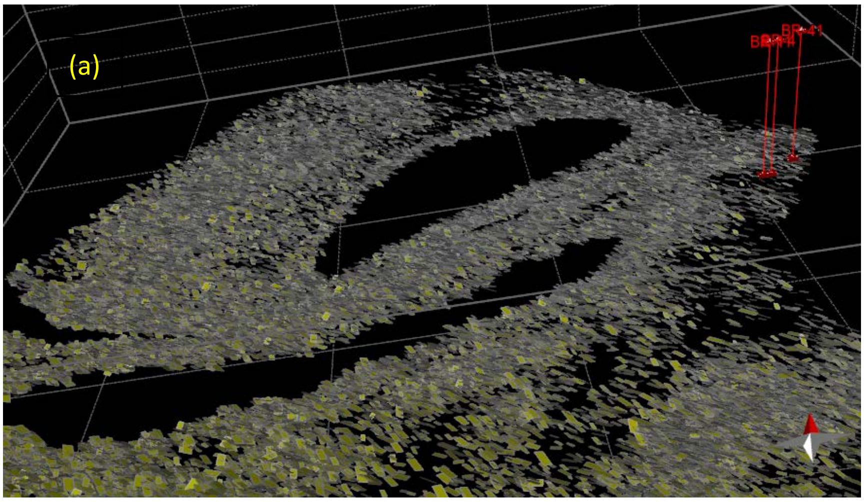
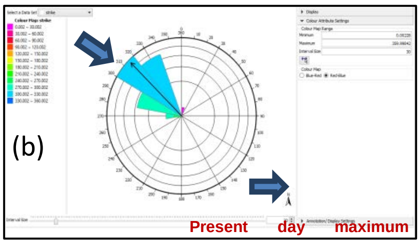


Fig.10: Map showing e1 distribution and fracture sets in geocellular volume. High fracture intensity/density is observed in high strain areas. These are concentrated in areas adjoining the major faults, fault tips and structurally higher zones.





Present day maximum horizontal stress direction

Fig.11. (a) Discrete fracture network generated by fracture modelling tool in constrained scenario. Few high producing wells from Borholla field is shown in the NE part of the map.(b) Rose diagram for strike of fractures shows that the fractures are dominantly oriented in NW-SE direction.This matches with the fractures observed in FMI log.