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Basement Tectonics in South Assam Shelf to decipher Promising Zones for Hydrocarbon Exploration: A GIS based approach

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Abstract

South Assam Shelf (SAS) represents a classical foreland basin with a Pre Cambrian basement that had undergone multiple episode of tectonism and is exposed in the Mikir and Shillong Massif areas. An attempt to combine outcrop based structural studies, morphotectonic analysis & GIS based collateral data sets to derive a geological model of the basement and identify areas for basement exploration has been made.

The Pre-Cambrian basement of SAS had suffered at least three major phases of folding of which the second phase of folding (F2) resulted in E-W planes of weakness. This defined the pre-dominant basement fabric that guided Phanerozoic faults. Tectonic fragmentation of the basement by Kopili Fault in Pliocene resulted in its tectonic fragmentation of it into Shillong and Mikir blocks. The Mikir block underwent clockwise rotation leading to dextral shearing along the E-W faults that caused extensive zones of fracturing in the basement. The clockwise rotation of Mikir block and Dhansiri Valley was accommodated by formation of Bomdila Lineament that might have affected the basement of northern part of the South Assam Shelf. Intersection areas of these two major fracture trends with NE and NS morphotectonic trends affecting basement can be considered as areas of maximum fracture porosity. GIS based areas of correlation having maximum fracture porosity with interpreted geomorphic highs, NW-SE faults acting as migration conduits may serve as interesting areas for future basement exploration in SAS.

Introduction

South Assam Shelf (SAS) encompassing the geographical extent of Dhansiri Valley forms a thrust-bounded basin that suffered multiple episodes of tectonism. It is flanked by NE-SW trending mobile Naga Schuppen belt to the east and southeast and Mikir massif to the west, whereas, Jorhat Fault bounds it in the North and separates it from the rest of Assam Shelf. Fractured Pre-Cambrian basement in the Borholla-Champang field bordering Naga Thrust forms a significant reservoir in the area with hydrocarbons assumed to have migrated from sub-thrust areas. Subsequent to Borholla, basement oil has also been discovered in the Khoraghat field, Dayalpur area and a number of wells in the basin implying other analogous areas that can be conducive for basement exploration. This paper is an attempt to build a geological model using remote sensing, morphotectonics and collateral studies and identify prospective areas of fractured basement.

Basement Tectonics

The Precambrian basement underlying SAS is exposed in the Shillong & Mikir massif areas, and had suffered multiple coeval episodes of tectonism resulting in a similar structural pattern. Stratigraphically, the basement is constituted of a metapelitic Basement Gneissic Complex overlain by a quartzitic Shillong Group that has been subsequently intruded by a number of Neo-Proterozoic granitic intrusions (Fig 1). Structurally the exposed basement shows a complex manifestation of polyphase deformations. In the Mikir Massif, three generations of folds are discernible (Prasad and Srivastava, 1987; Dotiwala et al., 1999) with the F1 phase showing tight isoclinal folds trending NNE-SSW. The F2 phase is tight sub-vertical with well-developed crenulation cleavage and axial traces trending E-W. The F3 phases are broad open warpings with a fold axis trending SE. Studies especially in Shillong Plateau by earlier workers indicate that the plateau is criss-crossed by innumerable faults and fractures with predominant trends in N-S and NE-SW. The N-S oriented fractures like Urn Ngot Fault and Dudhnai Fault cut almost the whole width of the plateau and are deep-seated as evident from magmatic intrusions along them.Satellite images also depict a prominent NE-SW trending deep-seated basement controlled Barapani Shear Zone with the effect of shearing evident even in the Mikir hills (Das et al., 1995).

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Post development of the Pre-Cambrian basement fabric, Gondwana grabens formed due to reactivation of basement trends resulting in E-W faults in northern and central part *(Dergaon-Jamuguri-East Lakhibari area)* and NE-SW faults the southern part *(Daldali area)* (Das et al., 2004).

Subsequently, in Oligocene compression and uplift related to Indian and Burmese plate subduction resulted in structural dissection of the entire basement in NE India along E-W, NW-SE and NE-SW trends. The Shillong plateau that emerged as a single outcrop of Precambrian basement rocks in Late Pliocene underwent tectonic fragmentation into Shillong and Mikir blocks due to effect of Kopili Fault that resulted in an approximately 300 km long and 50 km wide graben extending from Main Central Thrust to the Naga thrust. NW-SE fault systems were further reactivated due to severe compression associated with Naga Thrust dissecting earlier NE-SW longitudinal basin forming faults. Also at this time, major reactivation along the E-W Jorhat Fault took place probably due to loading by advancing thrusts sheets (Lahiri and Sinha, 2014). Movement across the Jorhat fault separated north and south Assam shelf, following which basement of North and South Assam shelf behaved differently (Kumar et al., 2011 and Kent et al., 2004).

All the above phases of tectonics in their respective time have affected the basement. Hence, sympathetic faults and fractures pertaining to each phase would create some amount of fracture porosity in the affected zones rendering those areas as probable areas of basement exploration.

Methodology

Since the SAS area has undergone multiple episodes of tectonism and is presently neotectonically active, it can be premised that basement related structural features are reactivated and represented on the surface as outcrop or geomorphic features. During the course of this work, a two phased approach has been carried out. Faults have been identified based on image data from features like sudden termination of outcrops (Fig 2a) and band tracing (Fig 2b) has been done from different image combinations & DEM data to identify various episodes of folding and relations between the different episodes of causative deformations. Additionally, extensive field work to identify structural features like joints, faults and shear zones in basement rocks has been carried out (Fig 2c).

The later part constituted morphotectonic analysis based on drainage and topographic derivatives to delineate faults and geomorphic highs (Figs 2d and 2e) in the basinal area. Such features are assumed as surface manifestations of deep seated faults and subsurface structural highs related to basement that reactivated under present stress regime.

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Figure 2a: Faults marked from LANDSAT 8 OLI data indicating clockwise rotation of NE-SW trends; 2b: Band tracing from different image composites indicating F2 phase of folding with E-W axial traces; 2c: two sets of joints N-S and E-W developed in granites on Guwahati-Jorhat road. The E-W joints are found to be vertical; 2d and 2e: Minor faults and geomorphic highs delineated from drainage 2f: Abrupt right angled turn in drainage in a 2^{nd} order channel near Titabar.

The morphotectonic interpretations (Fig 3a) are subsequently validated by extensive field checks (Fig 2f) where the mapped structures are checked for neotectonic imprints. These two parts were subsequently joined/ extrapolated and validated (Fig 3b) using collateral data to delineate the subsurface continuity/ disposition of the basement related structural features.

Discussions:

a) E-W Faults**:** Results from band tracing in Shillong and Mikir Massif indicate that the F2 generation of folding with E-W axial traces form the most dominant trend (Fig 4a) which implies that axial plane foliation corresponding to F2 folding will form the most dominant foliation in the area along which the later structures may be oriented. Correlation with the time slice of Borholla and Khoraghat at 1900 ms

(Fig 4b and c) indicates folded basement fabric with a dominant E-W oriented fold axis implying a F2 phase of folding. It also indicates a zone of E-W faults identified from morphotectonics parallel to the fold axis along which shear movement is apparent. Ant track data overlain on this zone is also found to indicate E-W oriented fractures. This might be a result of strike slip movement along the pre-dominant foliation defined by the fold axis of the F2 folds. Wells B-22 and B-26 aligned along these E-W oriented faults are also found to show predominantly E-W oriented fractures, along with subsidiary NW-SE faults (Fig 4d). This suggests that the E-W oriented faults are likely to play a major role in defining the basement fracture porosity in these areas. Cores recovered from basement in wells B-11 and F-3 (Figs 4e and f) also aligned along the E-W faults are characterized with strike slip movement and pre-dominance of vertical fractures along which maximum GYF is observed. In outcrop sections studied in Shillong and Mikir massif, E-W oriented fractures were found to be vertical. Based on the analogy, the vertical fractures in the recovered cores can also be conjectured to be E-W oriented.

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b) Rotation of Trends and Bomdila Lineament: The major lineament and tectonic elements in Shilong and Mikir Massif when correlated show a change in trend from NE-SW in the Shillong Massif to almost E-W in the Mikir massif (Fig 5a). This change in trend is attributed to clockwise rotation of Mikir Block post Pliocene as a result of Kopili Fault that split Kopili and Mikir massif in Late Pliocene (Duarah and Phukan, 2011). This rotation translated to shear movement or strike slip movement along the E-W oriented faults in the Mikir Massif and most probably in SAS. The effect of strike slip translational motion is also evident at the eastern edge of the Mikir massif, where different blocks appear to slip past each other. The causative strike slip faults may continue in basement of the basinal part resulting in fracturing of the area along its strike. Each of the E-W trends derived from Mikir Massif pattern also display a corresponding development of re-entrant in the Naga Thrust (Fig 5b).

To accommodate the clockwise rotation of Mikir and SAS block, a number of NW-SE faults may have formed in Assam Shelf. One such major fault is the Bomdila Lineament that forms a very regional tectonic element extending from MBT in Arunachal Pradesh to across the Naga Thrust. This lineament displays drainage offset in Bramhaputra River of about 22 kms and further southwards, signature of it are observed in drainage and also as a recess in the Naga thrust (Fig 6a). Effects of Bomdila Lineament are apparent in the northern part of SAS covering the regions between Borholla to Merapani fields. At basement level, the lineament forms a depression of at least about 5 km width (Fig 6b). Passive seismic shows that most of the earthquake epicentres are aligned along Bomdila Lineament with their foci extending to lower crustal levels. This implies that Bomdila Lineament reactivated multiple times and is presently still active resulting in fracturing of basement along its trend.

c) Areas of Maximum Fracturing and Promising Areas: From the discussions above, it is evident that the E-W oriented faults continuing from Mikir Massif to Naga Thrust along with the Bomdila Lineament forms the most fractured areas that have been repeatedly reactivated. Based on the morphotectonic faults, outcrop faults, gravity linears and faults from seismic along with the collinear notches in Mikir massif and Naga Thrust, a number of highly fractured zones are identified in SAS (Fig 7). Other than these E-W oriented fault zones, NE-SW basin forming faults, NW-SE faults to accommodate rotation and the N-S faults also exist in the area that might have affected the basement. Areas of intersection of all these phases of faults can be considered as areas of maximum fracture porosity. Empirically most basement reservoirs are considered to be a combination of areas of high fracture porosity coinciding with a basement structural high with younger sediments, which act as hydrocarbon sources, either flanking or directly overlying the basement. In this study, basement structural highs are found to be manifested as geomorphic highs. The orientation of Maximum Compressive Stress (SHmax) in a regional scale is found to be 148º or NW-SE, sub parallel to the orientation of the Bomdila Lineament. Faults oriented parallel to the SHmax are assumed to be open and hence act as conduits for re-migration. A GIS based correlation of the identified areas of maximum fracture porosity, interpreted geomorphic highs and NW-SE faults can be considered as optimal areas that meet the basement reservoir criterion (Fig 7).

Conclusions

F2 phase folding with an E-W axis defines the predominant foliation in the basement which guides the fracture pattern in the area. Kopili Fault in Late Pliocene caused the clockwise rotation of entire Mikir block and adjoining Dhansiri Valley. This clockwise rotation translated to a dextral shear movement along the E-W oriented faults in the SAS. These E-W trends remain the most reactivated trend resulting in zones of maximum fracturing in the basin. To accommodate the clockwise rotation, Bomdila Lineament is formed that affects basement fracture pattern in Borholla-Champang, Mekrang and Furkating areas. Areas of intersection of these two fractured trends with NE and NS morphotectonic trends can be considered areas of maximum fracture porosity. The areas of correlation with zones of maximum fracture density, interpreted geomorphic highs and NW-SE faults acting as migration conduits may serve as promising areas of basement exploration in SAS and define exploration strategy accordingly.

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