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A Kinematic & Geomechanical Restoration Approach for Tectonic Analysis and Basement Prospectivity, Cauvery Basin, India

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Abstract

In the present exploration scenario basement prospectivity is emerging as a frontier area for exploration and the same has been attempted in Cauvery basin through a basin restoration and strain analysis approach.
2D kinematic restoration across selected profiles orthogonal to Ariyalur-Pondicherry, Nagapattinam, and Tanojre sub-basins has provided insights into basin evolution and structurisation through geological time. Restoration studies in these sub basins, has brought out crustal extensions to the extent of 8.5%, 5.7% and 10.5%, respectively, due to oblique extension during rifting which is typical of an intra-cratonic rift and stretched crust.
3D geomechanical restoration at basement level in the study area has enabled capturing incremental and finite strain during restoration. Maximum strain values are observed in the vicinity of basement highs, major faults, fault intersections and other areas susceptible to faulting and fracturing.
A Discrete Fracture Network model was generated for NE-SW, E-W and NW-SE trending fractures, incorporating incremental Maximum Principal Strain (e1) as proxy to fracture density. NNW-SSE and N-W trending fractures were found to have high dilation tendency (>0.8) and are suitable to fluid flow.
The study has brought out prospective areas along basement related ridges, plunges and rising flanks of the Ariyalur, Tranqueber, Nagapattinam and Tanjore sub-basins.

Introduction

The Cauvery Basin a peri-cratonic rift along the south eastern coast of India with an area of approx. 70,000 sq. km. (Figure 1) and sediment thickness upto 6,000m ranging in age from Late Jurassic to Recent (Figure 2). A series of NE-SW trending horsts and grabens divide the basin into six sub basins, namely the Ariyalur- Pondicherry, Tranquebar, Nagapattinam, Tanjore, Ramnad-Palk bay and the Gulf of Mannar sub-basin. Hydrocarbon pools have been discovered in all the sub-basins in reservoirs ranging in age from Precambrian (basement) to Oligocene (Chaudhuri et al., 2010)
The petroleum system of basin envisages Late Jurassic to Early Cretaceous sediments within syn-rift sequences as major source, which reached peak HC generation within Early Cretaceous whereas some part of the basin attained maturity much later in Eocene and Oligocene.
In the present work, 2D Kinematic restoration of Syn and Post rift sequences has been carried out to decipher the different deformation stages and their implication on faulting and fracturing within basement. Predictive fracture models based on geomechanical restoration have also been generated.

2D Sequential Restoration

Sequential restoration along profiles covering Ariyalur-Pondichery sub- basin- Kumbakonam Ridge – Tranquebar sub-basin was carried out (Figure 3). The process involved removal of deformation, back stripping of younger horizons, decompaction, accounting for thermal subsidence for post rift sequences and isostatic balancing at each stage of restoration. The inferences obtained are given below

- Oligocene and Eocene restored sections show a single basin covering both the sub basins and a gradual shift of paleo shelf edge towards east since Mid. Eocene.
- Restoration at Albian top shows the existence of two independent marine sub basins with restricted syn-rift sedimentation. Kumbakonam horst remained a sub-aerial feature.

- Sequentially restored sections at Basement level for Ariayalur- Pondicherry, Nagapattinam and Tanjore sub-basins during rifting indicate crustal extension to be 7.8 km (5.7%), 3.4 km (8.5%) and 6.5 km (10.5%) respectively and beta factor (crustal thinning) of 1.3 to 1.77 indicating variable crustal stretching during rifting. The low beta factor and variability is attributable to oblique extension in an intra-cratonic rifting prevailing in Cauvery Basin.

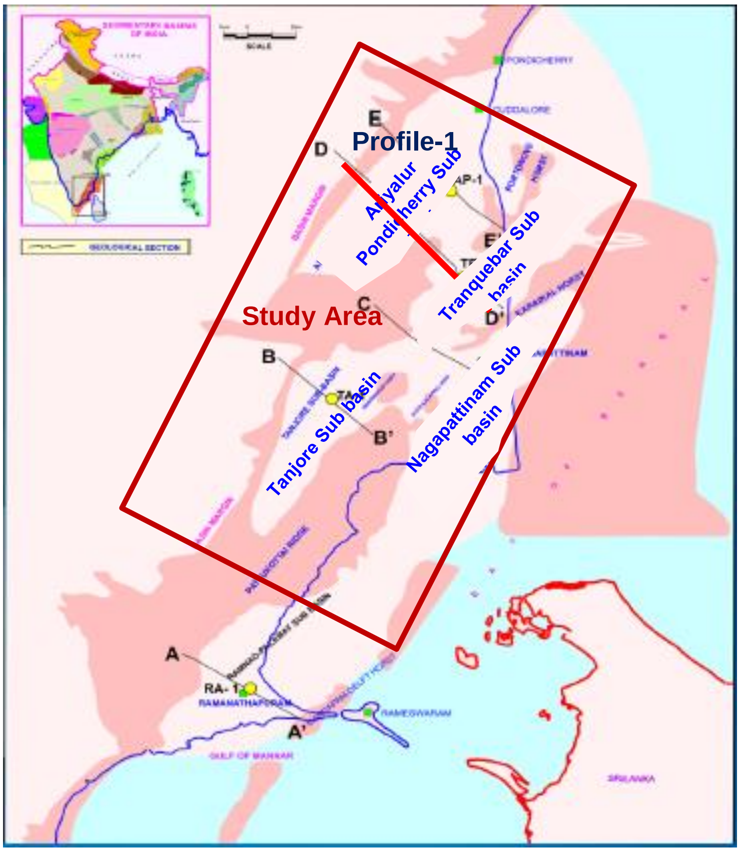


Figure 1: Tectonic map of Cauvery Basin showing study area

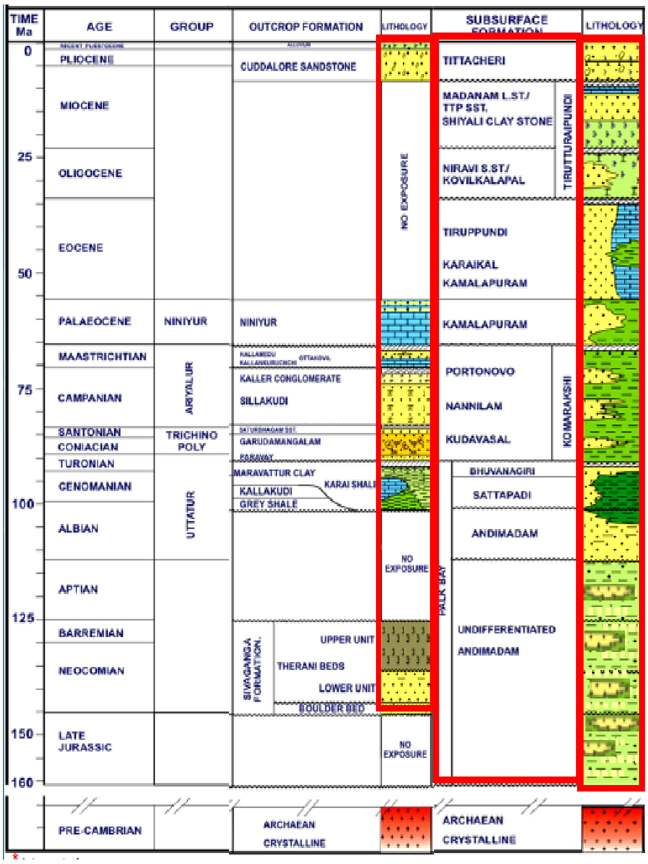
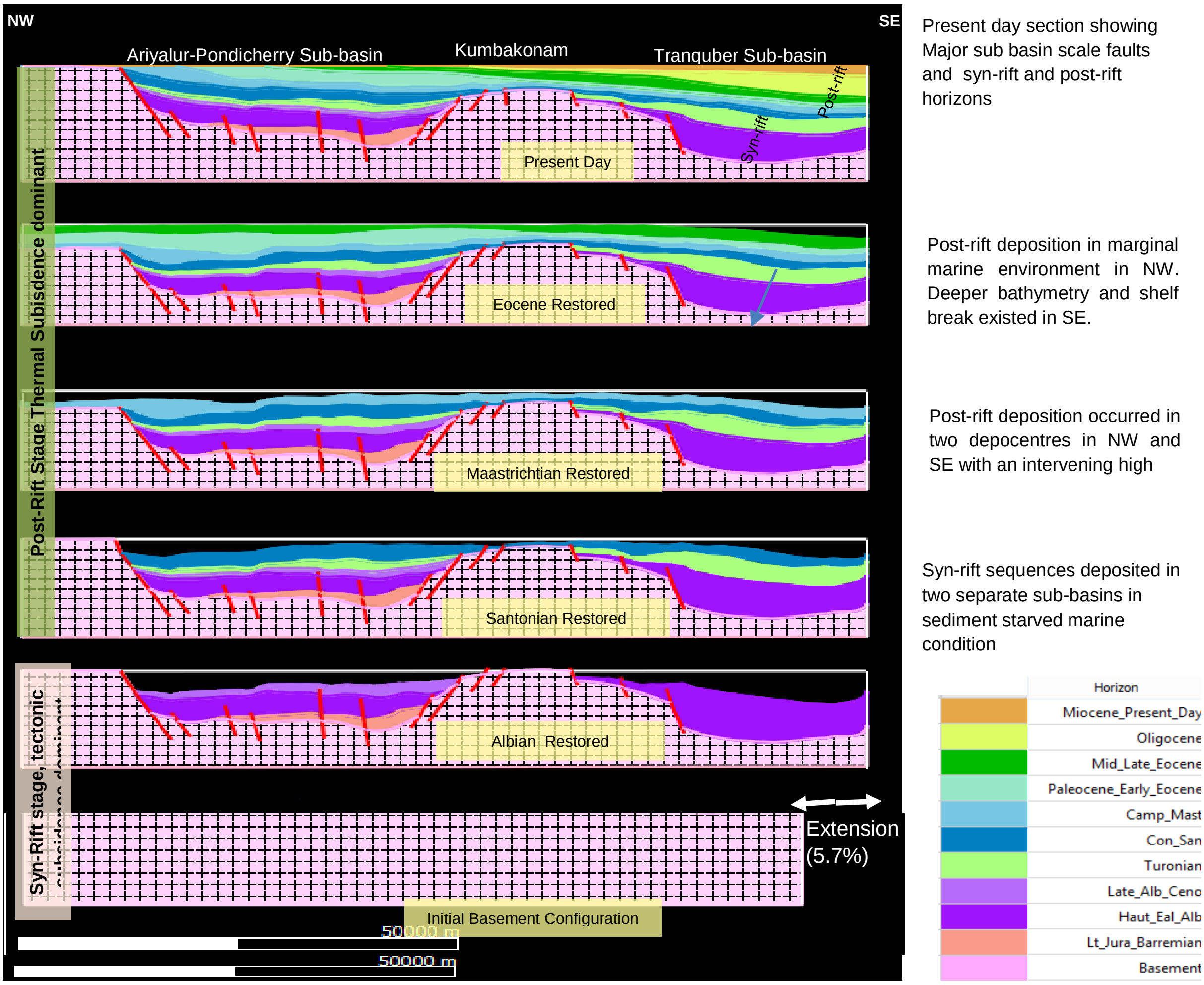


Figure 2 : Generalised Stratigraphy of Cauvery Basin (Source: Raja et al. 2011)

3D Geomechanical Restoration

Six horizon surfaces namely the Basement Albian, Turonian, KT, Eocene and Oligocene were sequentially restored by geomechanical method. Differential strain generated during restoration of deformed and faulted Basement surface to have been mapped and displayed at (Fig. 4). Following are the main observations:

- High strain trends are predominantly oriented NE-SW, E-W and NNW-SSE. Areas of high strain are observed to SE and SW of Madanam, North of Karaikal high, E-W trending zone between Kumbakonan, Karaikal and Pattukottai highs.
- The impact of Cauvery shear zone is seen in the form of E-W oriented high strain zones from Pundi-Mattur to Karaikal high.



	Horizon
	Miocene_Present_Day
	Oligocene
	Mid_Late_Eocene
	Paleocene_Early_Eocene
	Camp_Mast
	Con_San
	Turonian
	Late_Alb_Ceno
	Haut_Eal_Alb
	Lt_Jura_Barremian
	Basement

Figure 3: 2D sequential restoration of Ariayalur- Pondichery and Tranquebar sub-basins from present day to basement

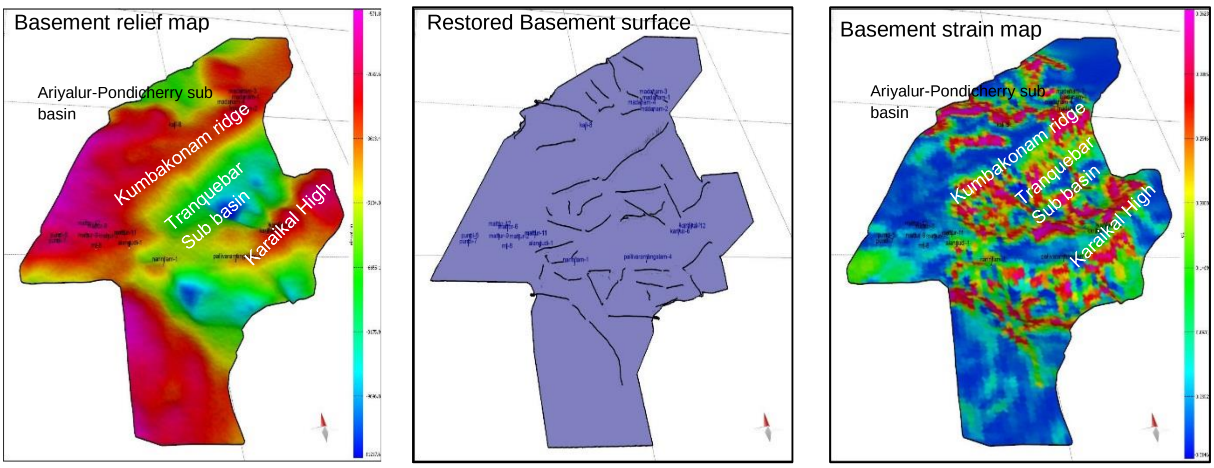


Figure 4: 3D geomechanical restoration of basement surface and captured differential strain.

Basement Fracture Characterisation

Detailed fracture analysis from FMI logs of study area shows NE-SW fractures with dips to NW (Lakhera et al., 2015). Another fracture set strikes ENE-WSW with two different dips to NNW and SSE (Figure. 5)

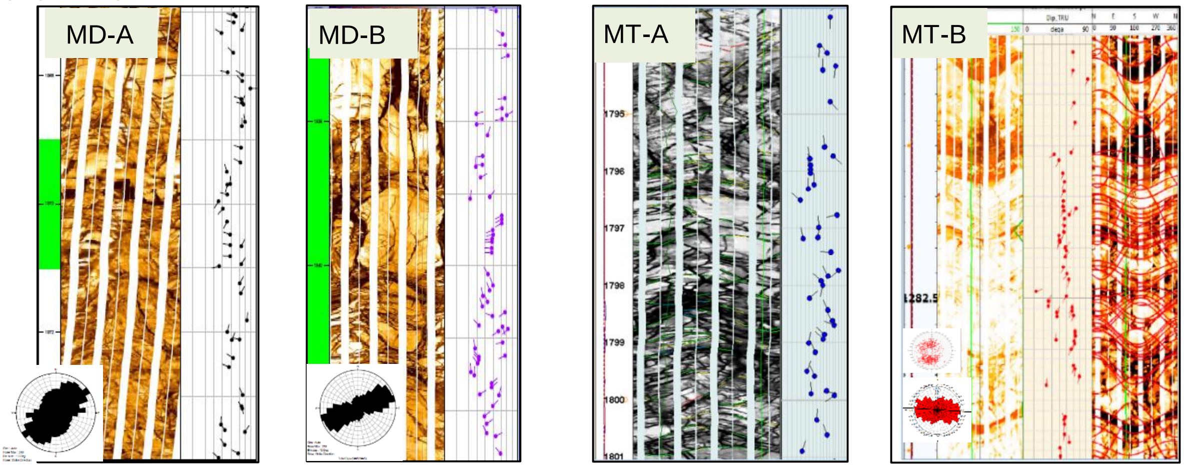


Figure 5: FMI logs from wells showing fracture sets in Basement. Rose diagrams for fracture strike show predominantly NNE-SSW, NE-SW and NW-SE trends.

Basement Fracture Model

A fracture model was generated with maximum principal strain (e1) values as proxy for fracture density within Basement (Figure. 6). In this model, three fracture sets are modelled with average strike in NE-SW, E-W and NNW-SSE; average dip of 47.09°, 37.29° and 52.20°; average dip azimuths of 184.22°, 290° and 94.67°; and Fisher values of 10.31, 9.34 and 9.19 respectively. Average fracture length was considered to be 200m and Power law with constant 'a' value of '2' as constant. Average fracture aperture was taken as 0.02cm in the model. A discrete fracture network model has been generated in a geocell of grid size 200*200*200m (Figure. 7).

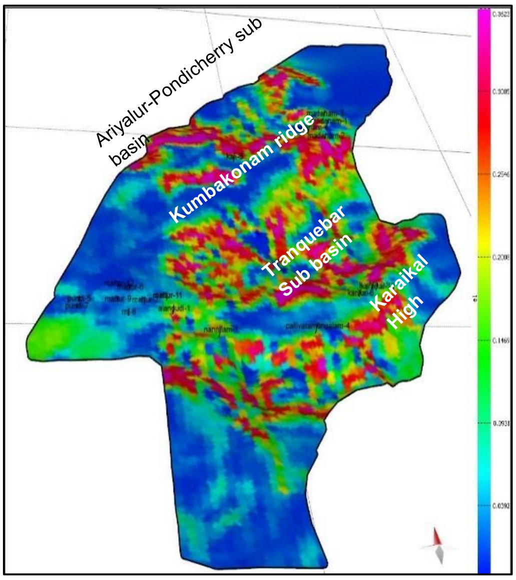


Figure 6: Geocellular volume populated with maximum principal strain (e1) for fracture modeling.

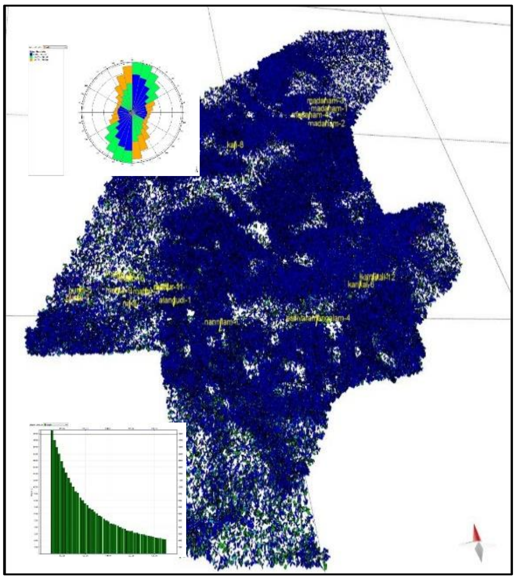


Figure 7: Constrained DFN model. Rose diagram for the strike of modelled fracture sets

Fracture Susceptibility Analysis

Critically stressed fractures (open mode stress state) are considered to contribute significantly to fluid flow in the reservoir. In this study, susceptibility of fractures to shear failure has been analysed by computing two geomechanical parameters viz. slip tendency and dilation tendency are estimated for modelled fracture sets in the prevailing geomechanical model at Basement depth (1500m and 2500m). The compressive principal effective stresses **σ'_1, σ'_2** and **σ'_3** at 1500m are calculated as 38, 14 and 11 MPa respectively. At the depth of 2500m depth **σ'_1, σ'_2 and σ'_3** are 56, 28 and 18 MPa respectively. Maximum horizontal stress orientation in N150^0 (Muller et al., 2015) is incorporated in the model for both of these depths. Maximum dilation and slip tendencies mapped for the fracture models are in the ranges 0.7-0.9 and 0.4-0.6 and are represented in the warmer colours (Figure. 8). It is observed that all the fracture sets have relatively higher dilation tendency as compared to slip tendency in present day stress regime. The rose diagrams for identified critically stressed fractures are found to be in NNW-SSE, WNW-ESE and NW –SE directions.

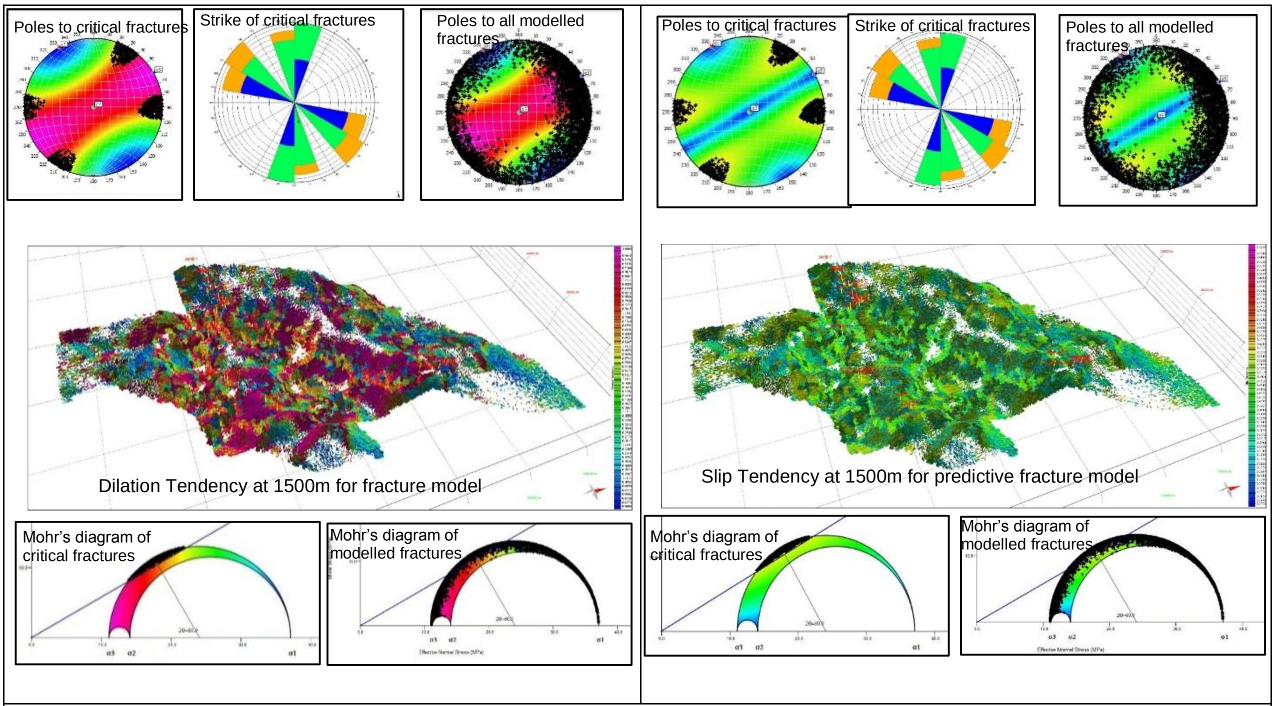


Figure 8: Dilation tendency and slip tendency for predictive fracture model at the depth of 1500m. Modelled fractures have higher dilation tendency than slip tendency. Critically stressed fractures are oriented in NNW-SSE and N-S direction. Fracture model with critically stressed fractures are seen in warmer colours.

Conclusions

1. 2D Kinematic restoration has enabled estimation of extension for Ariayalur- Pondicherry (5.7%), Nagapattinam (8.5%) and Tanjore sub-basins (10.5%) during rifting. The beta factor for these sub-basins is within 1.3 to 1.77, from basin margin to the centre. The low beta factor and variability is attributable to oblique extension in an intra-cratonic rifting.
2. 3D geomechanical restoration of Basement surfaces shows high strain zones trending NE-SW, E-W and NNW-SSE concentrated along major faults and associated highs.
3. Discrete Fracture Network model shows that fracture sets oriented in NNW-SSE, N-W and E-W directions have high dilation tendency (>0.8) and are suitable to fluid flow.
4. Integration of high strain areas with critically stressed fractures zones at structurally favourable areas has enabled identification of prospective locales on the Madanam ridge, Karaikal ridge, Tranquebar sub-basin's western and south western rising flanks and north eastern plunge part of Kumbakonam ridge.

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