A Remote Sensing and GIS based integrated approach for identifying promising areas for Basement exploration in Cauvery basin

S.Mazumder, BlecyTep and K.K.S.Pangtey
Remote Sensing &Geomatics, KDMIPE, ONGC
subhom007@gmail.com

Keywords

Basement, Shear Zone, Cauvery, Morphotectonics

Summary

The basement of Cauvery Basin had been affected by a two phase deformation during Pre Cambrian leading to development of E-W oriented shear zones. Based on morphotectonics, field data, image analysis and collateral data, a modeland map of the shear zone affected basement has been attempted. These zones had been interpreted to occur as individual bands of 250m to 400m thick, continuous from the basin boundary to offshore causing intense fracturing near basement top. Further episodes of tectonism during Phanerozoic affecting the basement had caused further fracturing of it. GIS based superposition of the high density areas of interpreted Post Pre-Cambrian fracturing on the interpreted shear zones produce zones of maximum fracture porosity. These fractured areas found associated with geomorphic highs that are considered to be manifestations of isolated basement highs and also occurring over or in proximity to source pods can be defined as promising areas of basement exploration. The E-W and NW-SE faults may have probably played a significant role in charging the basement reservoirs

Introduction

The Cauvery Basin forms a peri-cratonic rift basin (Fig 1a) where the major established hydrocarbon plays are limited to Cretaceous and Paleocene. However, recent hydrocarbon finds in the basement from Madanam, Pandanallur, Pundi and Mattur have indicated the existence of an additional basement play that might have a significant role in the overall hydrocarbon scenario. This paper is an attempt to identify areas of fractured basement and build up a geological model using remote sensing, morphotectonics and collateral studies that may serve as promising areas of basement exploration.

Basement Tectonics

a) **Pre Cambrian Tectonics**: The Southern Granulite Terrain (SGT) part of Dharwar Craton effectively forms the Basement of the entire Cauvery basin and is exposed in the western part of it beyond the basin margin. Tectonically, Dharwar Craton forms a stable continental region constituted of several Precambrian crustal provinces bounded by a number of shear zones (Harinarayana et al, 2006). Of these crustal provinces, the entire Cauvery Basin and parts of adjoining Palar Basin is found to occur within the domains of the Southern Granulite Terrane (SGT). As such, the structural fabric and the different tectonic elements pertaining to the SGT will have an impact on the basement fabric and subsequent tectonics affecting Cauvery Basin. The SGT itself is constituted of a number of accreted Pre-Cambrian juxtaposed crustal blocks which again are separated by a number of E-W trending crustal-scale shear zones that form the Cauvery Shear Zone (CSZ). The CSZ is a product of a two phase deformation during the Archean-Proterozoic boundary (D1) and Proterozoic-Cambrian boundary (D2) that affected about 150 kms length of Dharwar Craton, extending in betweenPondicherry to Pattukottai (Santosh et al., 2012). These shear zones area associated with deep seated faults affects the basement tectonics of Ariyalur-Pondicherry Sub basin, Kumbakonam Ridge, Tranquebar Sub Basin, Karaikal Ridge and Nagapattinam sub basin of Cauvery Basin (Fig 1b).

b) Post Pre Cambrian Tectonics: The Cauvery basin and the surrounding Dharwar Craton had also undergone a number of tectonic events in the Phanerozoic which can be assumed to have affected the basement

i) One of the events is the formation of N-S oriented faults during Lower Gondwana (Permo-Triassic, 250 Ma approx.) that are sympathetic to the opening up of the southern part of neighbouringPalar Basin.

ii) The principal event that affected and shaped the areas in Phanerozoic is the most dominant phase of rifting during Late Jurassic-Early Cretaceous. The initiation of this phase of rifting can be attributed to the fragmentation of Eastern Gondwanaland and resulted in formation of genetically related pull apart rift systems of Cauvery, Palar, Pennar& KG and NE-SW oriented down to basement faults in the area.

iii) In Lower Cretaceous, transpression along the junction between Antarctica and Sri Lanka-India led to development of a NNW-SSE trending transcurrent fault along which Antarctica moved southward (Lal et al. 2009). The combined effect of the ongoing activity of the NE-SW rift trend and NNW-SSE transcurrent fault led to the development of faults and structures of NW-SE cross trend.

All the above phases of tectonics in their respective time had affected the basement. Hence sympathetic faults and fractures pertaining to each phase might exist that would

create some amount of fracture porosity in the affected zones rendering those areas as probable areas of basement exploration.
Although Cauvery Basin rests on a basement believed to be stable Dharwar Craton, the area is neotectonically active from earthquake occurences in the area (Murty et al, 2002).

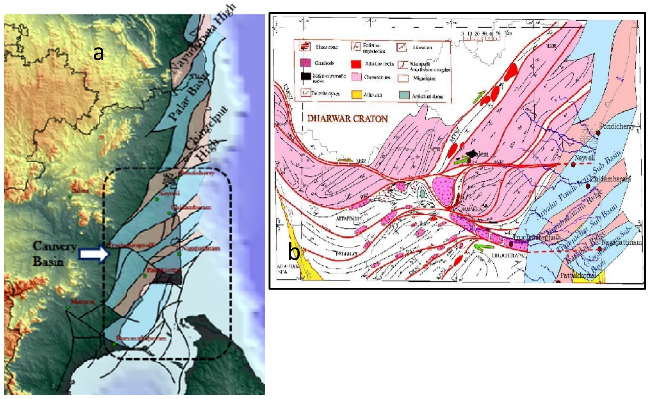


Fig 1a: General tectonic & geographical set up of East Coast India showing different basins and their dividing ridges**. 1b)** Layout of the CSZ (after Chetty, 2015) impacting basement tectonics of the northern ridges and sub-basins of Cauvery Basin..

Analysis& Methodology:
Since the study area comprises both the basinal and outcrop part, a two phase study had been carried out in the area. One part of the study comprises extensive field work and image analysis to identify structural features that are exposed in the basement rocks. The other part constitutes morphotectonic analysis based on principles discussed in Mazumder et al, 2012) to delineate subsurface structures in the basinal area. These two parts had subsequently been joined/ extrapolated using collateral data to delineate the subsurface continuity/ disposition of the basement related structural features. This had then been used to build up a regional geological model and delineate areas of basement exploration.

Morphotectonic analysis had been carried out for the basinal part to prepare a subsurface structural map. In this study, drainage, topography in terms of slope and aspect and LANDSAT ETM+ images had been analyzed for anomalies to delineate probable microfaults and geomorphic highs (Fig 2a and b). These features are assumed to be surface manifestations of deep seated faults and subsurface structural highs related to basement that had been reactivated under present stress regime. The morphotectonic interpretations are subsequently validated by extensive field checks where the mapped structures are checked for neotectonic imprints like unpaired terracing, abnormal incisions and braiding.

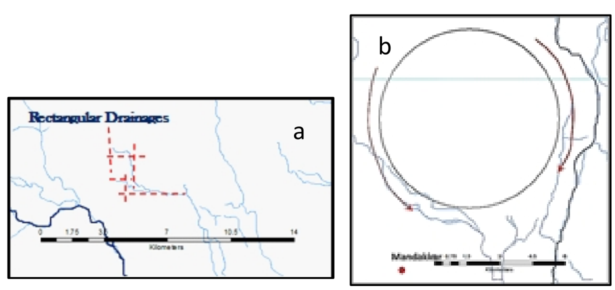
In the other part of study, imageries of basement outcrops beyond basin margin had been interpreted for identifying abrupt termination of outcrops to decipher faults (Fig 2c) and to identify instances of foldings in basement (Fig 2d). Based on fieldwork in the outcrops, attitude of joint sets developed in basement lithology had been measured to identify trends of their causative regional faults (Fig 2e). In case the trend and disposition of the joint sets are found to correlate with the trend of the morphotectonically interpreted faults, then the corresponding faults identified in the basinal and outcrop part arevalidated. Outcrop areas that suffered deformations like folding, faulting and shearing were analyzed. The variations in geometry and trends of the structures in basement lithology resulting from the deformations were noted in field (Fig 2f). These structural variations in outcrop scales were then compared with geophysical (seismic and log data) and regional scale image data to draw an analogy

Correlation & Modelling with Collateral data

For a further level of validation and to establish the subsurface continuity of the features in the interpreted map (Fig 2f), the structures are correlated with collateral data.

For an initial level of correlation, the faults mapped using morphotectonics was overlain with faults that had been mapped at basement top in different fields. The correlation indicates most of the faults at basement top level are represented at the surface level suggesting that the surface faults are manifestations of faults at basement top level (Fig 3a). A trend based correlation however suggests that the E-W trends are more reflected in the surface manifestations implying similar such E-W faults in sub-seismic resolution might exist in basement top level.

Additionally, seismic time slices of Kuthalam and Madanam area at 2000 ms depth had been mosaicked with ant track data pertaining to basement of Madanam and Pandanalur for a regional idea about basement surface.This was subsequently processed to extract lines of higher seismic amplitude (Fig3c).



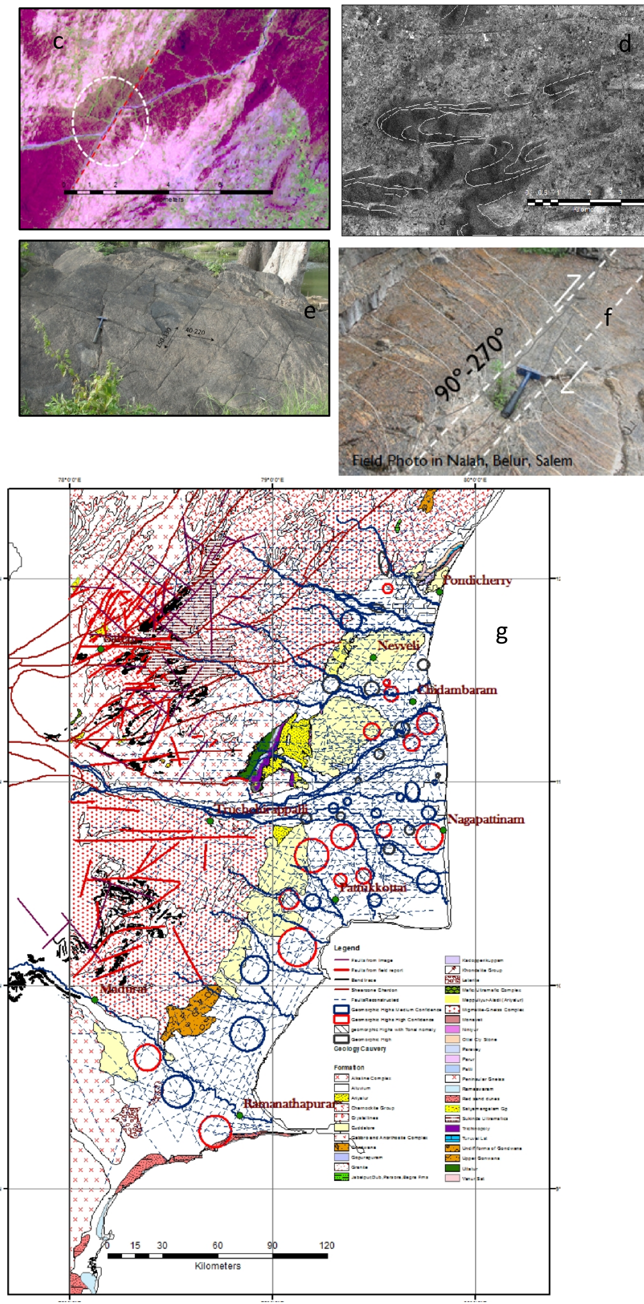


Fig 2a and b: Morphotectonic interpretations of microfaults and geomorphic highs assumed to be manifestations of subsurface faults and structural highs **2c and d)** LANDSAT ETM+ image based interpretations of faults and foldings in basement **2e and f)** Field examples of joint sets and defoemations due to shearing **2g)** Final map prepared on basis of morphotectonic interpreatations, fieldwork and image analysis

These lines are found to define a highly folded layerwith almost E-W axial traces thus defining longitudinal sheath folds. These folds can be considered to be contemporaneous with the shearing activity and hence are indicative of E-W shear mechanisms in basement of basinal part. These folds defined from seismic appear to be very similar and bear a corresponding relationship to the folds defined from image andthose observed in outcrops during field checks. Hence the causative shear zones may be considered to be continuous from basement to basinal part (Fig 2d).

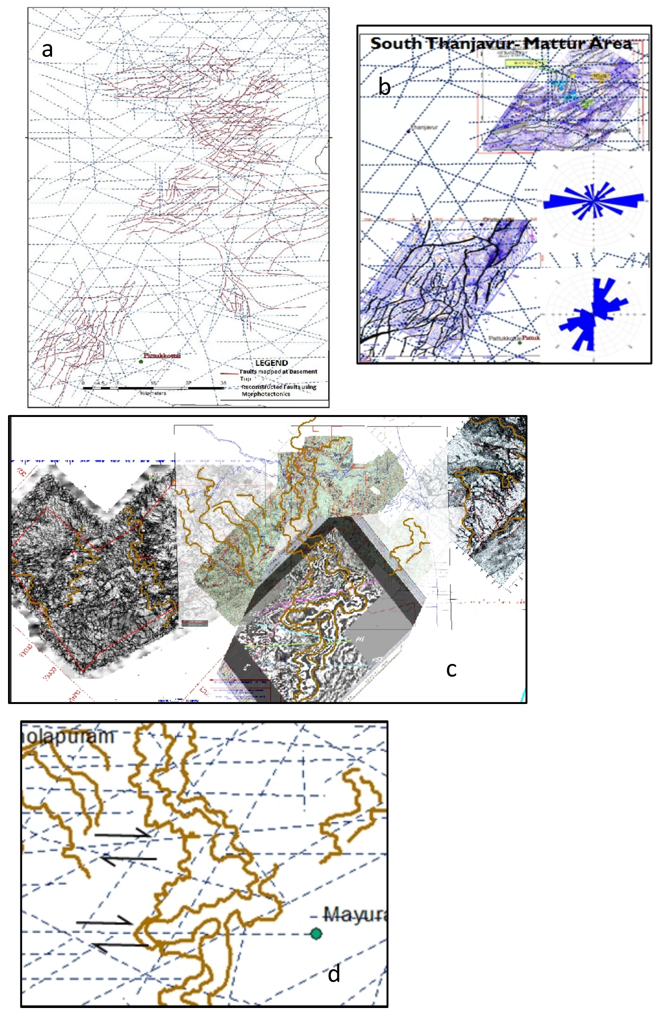
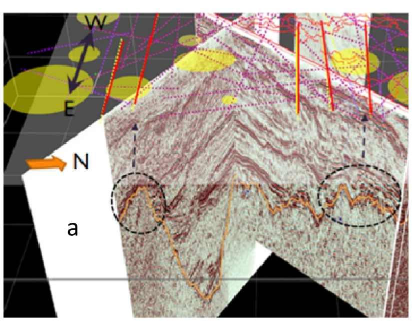
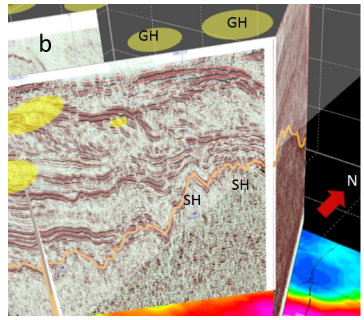


Fig 3a: Morphotectonic interpretations of faults correlated and validated using faults mapped on top of basement. **3b)** Trend based correlation of surface (on top) and basement (below) indicating E-W trends are more manifested on surface 3c) Seismic time slices of Kuthalam and Madanam area at 2000 ms depth and ant track data pertaining to basement of Madanam and Pandanalur processed into a seamless mosaic 3d) Lines of high amplitude defining sheath folds with E-W axial traces

Sectional data were also correlated with these surface interpretations to understand the basement top morphology and realize its manifestations in the morphotectonic data. From the correlation it is observed that most of the geomorphic highs interpreted from the morphotectonic data are found to be related with the areas of basement structural highs (Fig 4a). Other than these structural highs, the basement top also depicts a series of smaller undulations with a much smaller variation in basement relief compared to the structural highs. These small undulations are found to correlate with the sheath folded layers delineated above. Also the individual undulations in the series are found to be separated by the E-W trending faults. Since both the sheath folded layers and the E-W trending faults are associated with shearing, it might be construed that the series of small undulations at the basement top level are representative of shear zones(Fig 4b). This again implies the continuation of the shear zone,Similar patterns of undulations associated with shearing had also been observed in outcrops during field work (Fig 4c).

In order to correlate fracture data at basement level with surface interpretations, FMI data of M-5 and M-6 associated with E-W faults were analyzed for fracture orientations.A trend analysis was done for every 50 m interval from basement top for both the wells and the results were correlated (Fig 5a).From trend analysis as well as from field analogues, all intervals that show maxima of E-W trending fractures and association with E-W oriented foliations in FMI images are presumed to be associated with shear zones. These E-W trending zones occur as areas of 200-250 m thick with the areas in between showing other tectonic trends representing un-sheared rock with no planar structures (Fig 5b). A stereoplot of the E-W trends shows that these structures show a high amount of dip (approximately 60°) dipping northwards.As such, these shear zones could have branched out of a thicker and deeper shear zone where more than one shear zone could be encountered in a particular well (Fig. 5c).





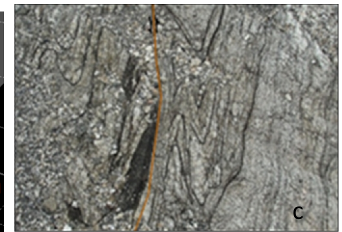
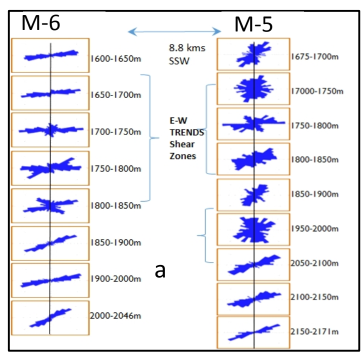
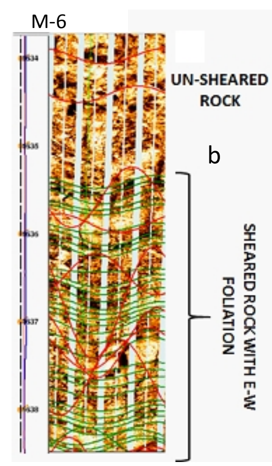
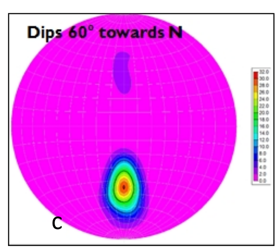


Fig 4a: Structural highs at basement level (SH) found to be correlating with surface geomorphic highs (GH) **4b)**Smaller series of undulations at basement top with low relief variation, with the individual undulations separated by E-W faults and correlating spatially with the sheath folded layers **4c)**Undulation in basement top morphology presumed to be associated with shear zone observed in field in Manamedu near Trichy

In addition, DSI logs of P-6 also occurring in a shear zone had been correlated with the FMI logs. The intervals showing development of E-W trending foliations in basement in FMI along which the fractures had been assumed to form had been compared to corresponding sections of DSI log. The Stoneley Reflection coefficient those zones interpreted from the DSI logs implies that the interpreted fractures are open and deep (Fig 5d). A similar phenomena had also been observed in the basement outcrops







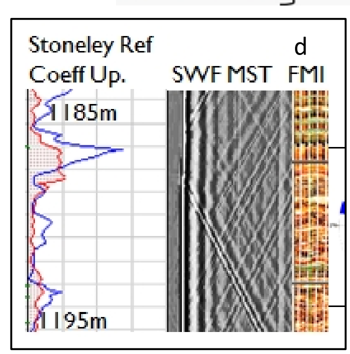


Fig 5a: Trend analysis of fractures at every 50 from basement top identified shear zones of about 200-250 m with dominance of E-W fractures in wells M-6 and M-5**5b)**FMI data showing gneissosity developed in the sheared portion oriented E-Wwithunsheared part devoid of any such foliations in M-6**5c)**Attitude of E-W fractures showing an approximate dip of 60°northward 5d) DSI & FMI of basement section of P-6 indicating E-W trending fractures associated with shear zone developed foliations are open and deep

Considering E-W trend to be reflective of shear zones, signatures of E-W trending faults affecting basement were derived for the shear affected zones from (i)E-W trends from gravity derivative (Fig 6a)and horizontal gradient map (ii) E-W trends from aero-magnetic data (Fig 6b) and offshore magnetic data (iii)E-W trending faults from seismic maps at basement top (iv) Shear zones mapped in field (v) Morphotectonic data. All these were used as building blocks for the re-construction of shear zones in the area (Fig 6 c and d. Since only the northern part of Cauvery Basin between Pondicherry to Pattukottai are affected by shearing, this remains the more suitable area for basement exploration.

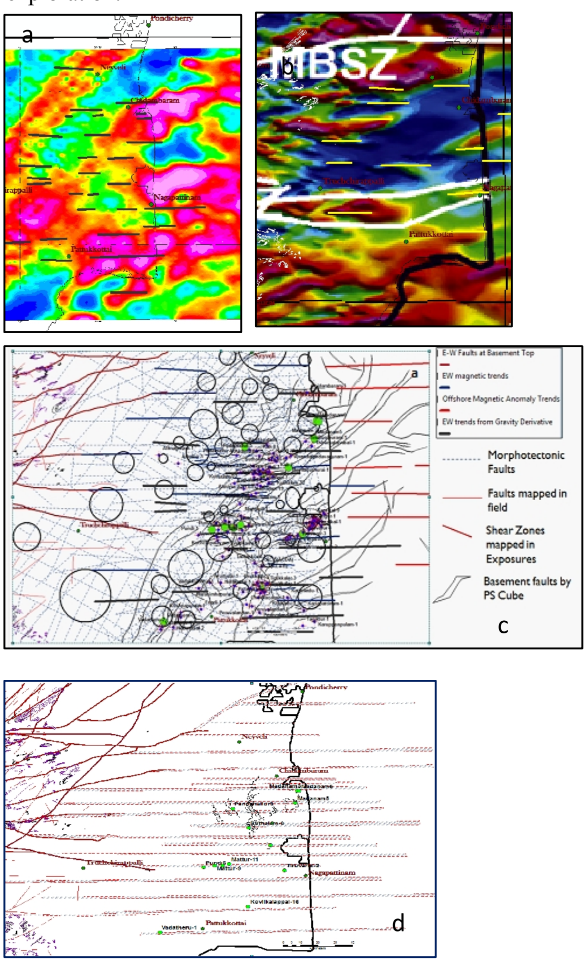


Fig 6a and b)E-W trends derived from gravity derivative and aero-magnetic (Rajaram et al, 2014)**6c ansd d)**Datasets pertaining to E-W faults affecting basement used as building blocks to reconstruct the E-W shear zones

Discussions

Model: The Pre-Cambrian shear zones are considered products of ductile deformation with the concentration of large strain. With decrease in depth and associated decrease in temperature and pressure, wider zones of ductile displacement are transformed into discrete planes and narrow zones of brittle displacement. In the present case, shear zones in the basement of basinal part can be considered as highly brecciated/ fractured areas of about 250-300m thickness affecting basement. Each of these shear zones are found to extend E-W continuous from the basement exposures to basinal part. Since these shear zones are steeply dipping and believed to have branched out from a single zone multiple shear zones could be encountered in a well as fractured areas while drilling the basement (Fig. 7a).

Post Pre-Cambrian Deformations & Fractured Areas: Other than shearing, the basement had also suffered faulting and fracturing due to episodes of Post Pre-Cambrian tectonism discussed earlier. Since all this phases of faulting had affected the basement, it will cause some amount of fracturing sympathetic to the fault trends. Density analysis and fault intersection countof faults interpreted from morphotectonic analysis had been carried out for these Post Pre-Cambrian trends and areas of high fracture density delineated. If these fractured zones are overlain on earlier established shear zones, zones of intersection might be considered as areas which have the highest fracture porosity in the basement (Fig7b).

In-situ Stress, Reactivation and Migration: Since the morphotectonic faults are products of neotectonic reactivations, a trend analysis for the interpreted faults shows E-W faults are the most reactivated trends under present stress regime. The in-situ stress direction (S_{Hmax}) as deduced from Drilling Induced Fractures in M-5, World Stress Mapsand focal plane solutions (Murty et al, 2002) is found to be oriented in a NW-SE to ENE-WSW direction.

For Cauvery basin, shales within Andimanam Formation and SattapadiShales of Cretaceous are considered the main source horizons. The critical moment is observed around 65.5Ma.Since after Early Cretaceous, no major tectonic event occurred in the basin, the in-situ stress direction is considered similar to that prevailing atthe time of migration (Phaye et al, 2011). On this assumption, based on principles in Zhang et al, 2011, E-W faults may play a significant role in charging basement reservoirs by updip/ lateral migration from adjacent kitchen areas into structural highs (Chandrasekhar at al, 2015). This postulation is also corroborated by association of adsorbed gas anomalies with interpreted E-W shear zones (Fig7c)

Promising Areas: Most basement reservoirs are considered as combinations of a) a basement structural high as well as a b) highly fractured area with c) hydrocarbon sources either flanking or directly overlying the basement connected with d) migration trends. Hence, areas which show a correlation of identified fractured areas with interpreted geomorphic highs (assumed to manifestations of basement structural highs) and overlie or occur in proximity to source pods connected by E-W and NW-SE faults can be considered as most promising areas that meet the basement reservoir criterion (Fig 7d).

Conclusions

From the above analysis, a probable basement isproposed with E-W shear zones that occur as individual bands of 250m to 400m thick, spaced apart by 500m to few kms, steeply dipping near basement top and believed to branch from a deeper and thicker ductile shear zone.These shear zones affect the basinal basement between Pondicherry to Pattukottai and cause intense fracturing near basement top.

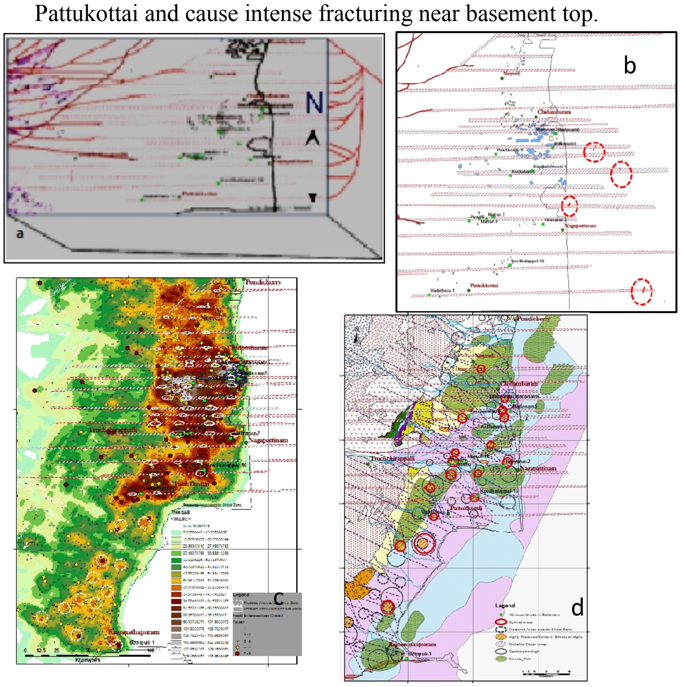


Fig 7a) Probable model of arrangement of the shear zones branching off from a thicker and deeper shear zone **7b)** Ethane (in blue) and propane (in green) anomalies and offshore seepages found to be oriented and associated in the same direction as the E-W shear zones 7c) Areas of high fracture density delineated with the areas of intersection of Post Pre Cambrian trends with shear zones considered areas of maximum fracture porosity 7d) Highly fractured areas associated with basement structural highs in the study area thus fulfilling the characteristics of basement reservoir

Post Pre-Cambrian tectonics superposed on the shear zones cause further fracturing of basement and thus may produce zones of maximum fracture porosity. These areas in conjunction with basement structural highs and proximity/connection to the source rocks are considered to be potential areas of interest in basement exploration.

Acknowledgements

The authors express their gratitude to GGM-Head of the Institute, KDMIPE and GM-I/C Geology Group for their kind permission in publishing & presenting this paper.

The views expressed in this paper are those of the authors and not necessarily that of the organization they represent.

References

Chetty T. R. K., 2015, The Cauvery Suture Zone: Map of Structural Architecture and Recent Advances, Journal of Geological Society of India, Vol. 85, pp 37-44

Harinarayana T., Naganjaneyulu K. and Patro B. P. K., 2006, Detection of a collision zone in south Indian shield region from magnetotelluric studies, Gondwana Research, Vol. 10, pp 48-56

Mazumder S., Dave H. D., Samal J. K., Mitra D. S., 2011, Delineation of shallow structures as exploratory input in Ganga Basin based on Morphotectonic studies, ONGC Bulletin, Vol 46, No 2, pp 190-198

Murty G. P. S, Subrahmaniyam A. S., Murthy K. S. R and Sarma K. V. L. N. S, 2002, Evidence of fault reactivation off Pondicherry coast from marine geophysical data, Current Science, Vol. 83, No-12, pp 1446-144

Phaye D. K., Nambiar M. V., and Srivastava D. K., 2011, Evaluation of Petroleum Systems of Ariyalur-Pondicherry Sub-basin (Bhuvangiri area) of Cauvery Basin, India: A Two Dimensional (2-D) Basin Modeling Study, AAPG Search and Discovery Article #90118

Rajaram M. and Anand S. P., 2014, Aeromagnetic signatures of Precambrian shield and suture zones of Peninsular India, Geoscience Frontiers, Vol 5, pp 3-14

Santosh M., Xiao W. J., Tsunogaed T., Chetty T. R. K., Yellappae T., 2012, The Neoproterozoic subduction complex in southern India: SIMS zircon U-Pb ages and implications for Gondwana assembly, Precambrian Research, 192-195, pp 190-208

Zhang L., Luo X., Guy V., Yu C., Yang W., Lei Y., Song C., Yu L., Yan J. 2011, Evaluation of geological factors in characterizing fault connectivity during hydrocarbon migration: Application to Bohai Bay basin, Marine and Petroleum Geology, 28, pp 1634-1647

Chandrasekhar N., Mane P.H., Rajappan P., 2015, Basement hydrocarbon Exploration- Overview of Basement Exploration, Multicomponent Seismic Analysis, Identification of fractures and Status of Indian basin exploration, Geohorizons, pp-36-46