

dominated section shows GYF/mild cut witnessed the envisaged situation of fractured area.

Regional set up:

Contiguous basin (Bangladesh-Arakan Yoma) having with same genesis and source parameter suggest that Kopili is the main source for the basin.

Regional understanding at Paleocene-Eocene level of the basin has been studied with contiguous nearby set up Sylhet trough and Patuakhil depression. A schematic diagram is shown for technical understanding (Fig. 2).

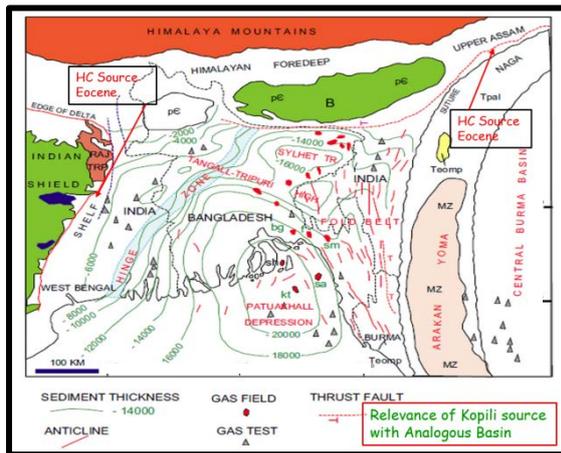


Figure 2: Regional Setup (After Sofiquel Islam)

Well data review:

Around 20-25 wells, have been drilled in Geleki field and very few wells penetrated complete Kopili sequence. LOS of few key wells were selected and examined in the study (Fig. 3).

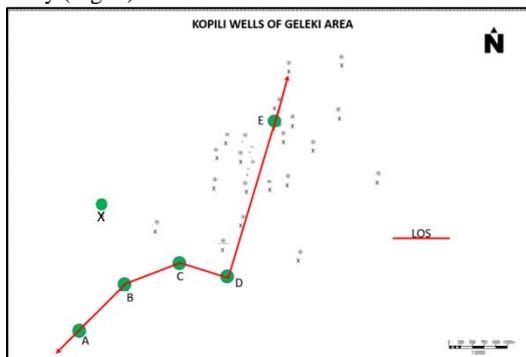


Figure 3: LOS across wells drilled through Kopili

Well-A: The well is located extreme SW part of Geleki field drilled to a depth of 5130m to explore Tura and Kopili Formation where Kopili top is encountered at 4517m and more than 500m of the sequence is penetrated. The sands within Kopili in the interval 5080-5067 tested as water bearing. Many Sub Vertical Fracture (SVF) and Strata Bound Fractures (SBF) are deceptive in Kopili shale section. Shale are splintery, silty and carbonaceous (Fig. 4). In the well section a conventional core was cut in the interval 4805-4814m shows mainly shale and thin sand. The litho-unit below in the interval 4825-30 in cutting samples with more than 90% is shale

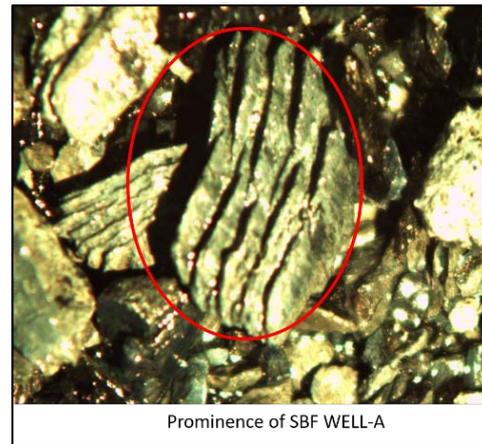


Figure 4a: Interpreted Sub Vertical Fracture (SBF), Well A (4717-4368m), Mid-Late Eocene

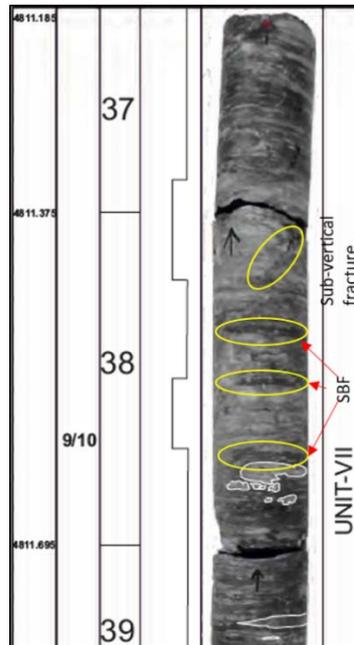


Figure 4b: Combination of SBF and SVF in core of Well A

Well-B: The well is drilled to a depth of 4730m SW of Well-C where Kopili top is encountered at 4230m. The sequence encountered below 4500m is more of shaly and observed mild fluorescence and cut. The situation is only possible due to the presence of fracture permeability of shale

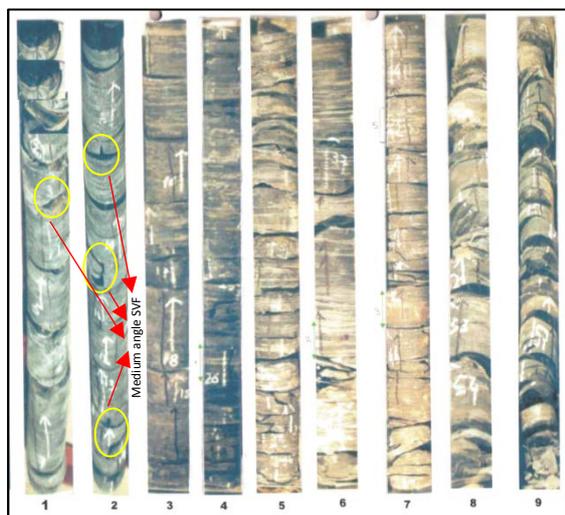
Well-C: The well located in SW part of the field tested for the first time and produced oil/gas from Kopili sand. Kopili top was encountered at 4085m and completed at 4510m. The cutting and core samples were reviewed. Many shale samples shows fluorescence and +cut.

Further, the cored section in the interval 4166-4175m dominated by more than 50% shale with minor coal and very thin sand shows strong GYF observed presence of fracture component in shale.

Well-D: Another Kopili well section drilled up to 4500m, SE of Well-C was examined where Kopili Formation top is encountered at 4244m. The presence of HC is also observed in the interval dominated by Shale. The drilled sequence 4240-4250, 4275-4285, 4304-4325 and 4340-4335m dominated mainly shale sequence confirmed the presence of fluorescence and cut.

Well-E: The well drilled up to the depth of 4800m in the main Geleki structure, the complete Kopili Formation was penetrated with a thickness of more than 700m. The Middle and Lower Kopili section is shale dominated and more than 500m thickness is encountered in the well. Shales are characterised by grey to dark grey in color, silty, feebly calcareous, and splintery and witnessed micro-fractures.

Besides the LOS a well **X (ref-location map)** drilled to a depth of 4996m N-NW of well-B up to Kopili Formation. A core CC-2 (4856-4865m) was cut. The cored section studied and inferred that the upper part of the core consists of dark grey hard and compact poorly fissile shale with silty laminae, sideritic at place. Middle part exhibits soft sediment deformation and lower unit consists of dominant gray shale with very thin silty lenses.



Core order shown here from bottom to top (1-9). Bottom part is the shale dominated sequence showing indication of medium to high angle sub vertical fracture.

The well data analysis and records of HC shows/fluorescence and positive cut in Kopili shale sequence observed and fracture permeability envisaged. The finding warrants further analysis of other parameters to relook and establishing shale fracture play.

Sedimentological studies:

The lithofacies of Kopili Formation deposited over the Sylhet regional Unconformity during Middle to late

Eocene under shallow/marginal marine to lagoonal/intertidal to subtidal condition and is associated with shales and thin interbedded limestone towards bottom and sand/shale alternations in the top. Detailed study was constrained due to limited numbers of core available in Upper Kopili section while in lower Kopili Formation no conventional core was available in study area. The Well “E” is a key well which has penetrated the complete Kopili sequence and a conventional core taken (4446.3-4451m). The sequence is characterised by heterolithic facies of silty shale, splintery, carbonaceous, soft sediment deformation and exhibits signature of micro-fracturing typical of a tidal flat environment. Kopili, as a mega unit in Geleki can be divided into upper and lower units. Upper Kopili is dominated by sand/shale alteration containing sporadic benthic Foraminifera while the lower unit is dominated by shale associated with larger foraminiferal Nummulites. In context to sedimentological findings, well fracability for commercial production to be advantageous due to splintery/silty nature of shale.

Geochemistry, fluid property and envisaged oil / gas window:

Kopili shales contains mainly contains Type-II and minor Type-III Kerogen, rich in hydrogen content and characterised by its pure monomaceral form of exinite. Organic matters are dominated by sapropelic-algae. The Type II kerogens are derived from spores and pollen grains of land plants, marine phytoplankton cysts, leaf and stem cuticles confirming high biological productivity due to nutrient supply, low mineralogical dilution, and restricted oxygenation in Kopili Formation. Effective source facies is Oil prone. Hydrocarbon play type in the concept thought of as challenging reservoir and hydrocarbon type is “light-tight oil prevailing within Kopili source facies. Thermal maturity (VRo) of Kopili shale ranges from 0.6-1.3. Based on the data review, oil / gas window and API characteristics is shown here (Fig. 5 & Fig. 6).

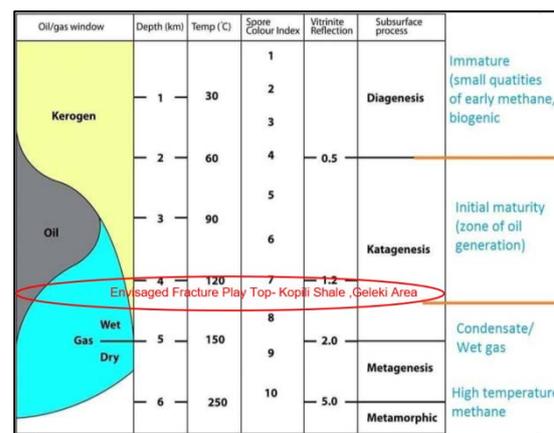


Figure 5: Oil and Gas Window

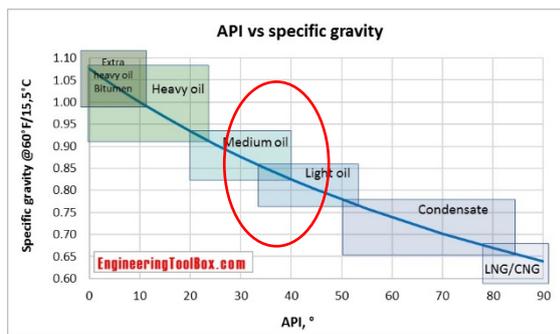


Figure 6: API range of Kopili Oil

The quantum of movable hydrocarbon expected maximum upto 30% from the model depending upon nature of shale from the generation window by strata bound fracture and micro-fracture path generated all along Naga thrust corridor.

Seismic expression and log signature: Seismic expression of well-D which penetrated the complete Kopili section (Target area) in main Geleki structure is witnessed more than 500ms pack shown here in the Fig. 7 below.

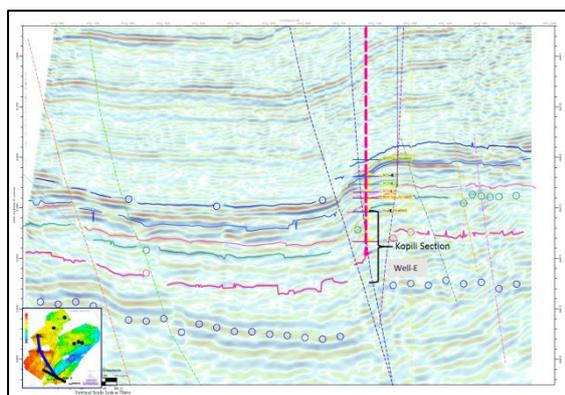


Figure 7: Seismic signature passing through complete Kopili pack in Well E

Further, increasing trend of pack thickness also demonstrated by electro log correlation across Disangmukh, Rudrasagar, Charali field and well-E of Geleki fields in Fig. 8.

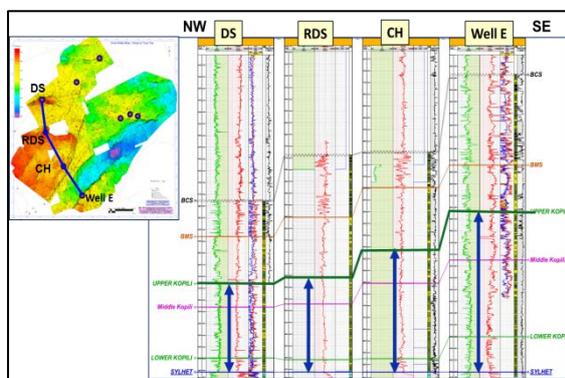


Figure 8: Electro-facies variation showing thicker shale in Well-E

Manifestation of fracture type reported in Lower Cambrian shale -SE Chogqing, China and examples of other global acreage:

In Lower Cambrian shale sequence of SE Chongqing of China province, technical evaluation of fracture type reported with comprehensive understanding for shale gas by Dahua Li in 2015. Fracture pattern records established in the study are as structural fractures, diagenetic fractures and abnormal pressure fractures and the interrelationship with each other. The study further inferred that high angle shear fractures (75-90 degree) are most common and widely developed. On same corollary, the situation is relooked for Kopili shale. Pictorial records of studied core samples are shown here in following figure (fig.9).

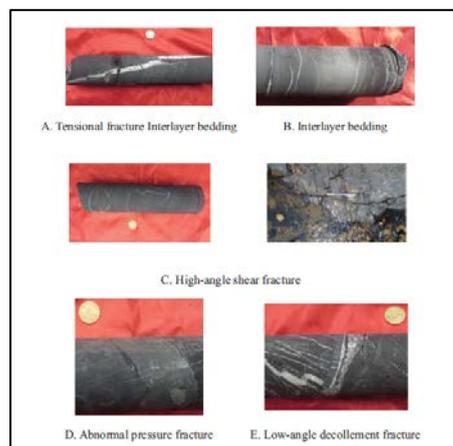


Figure 9: Genetic fracture type - Cambrian shale, China province

Further on commercial implication, quite a number of global acreages having evidence of shale microfractures are reported in public domain (Weald Inversion structure-Cretaceous oil, English Channel inversion Jurassic oil, etc.) that acts as reservoir pay and producing light tight oil. A classic example in present aspect where field Operators are concentrating their efforts showing here with Chronostratigraphy superimposing with Iso VRo map, the Triassic shales of Vaca Mureta Fm. Argentina, (Fig. 10) for understanding and perception.

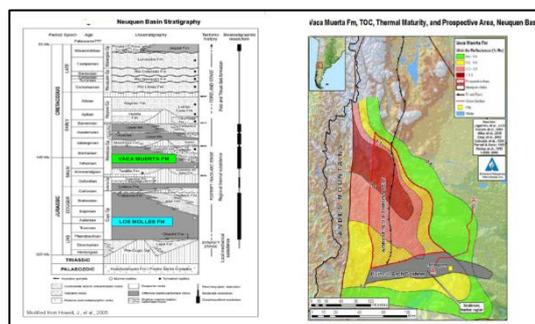


Figure 10: Vaca Mureta Stratigraphy

Target Window and Schematic Model:

In present context the Kopili shale in the Geleki area all along the Naga thrust zone may be a feasible future business and taken up as a case study. The most successful shale fractured reservoirs envisaged in the area of inversion, i.e. the extent of Geleki inversion require to review for pilot. The red circle marks the area of primary migration impacted by stress field of Naga thrust locked with substantial volume of hydrocarbon, is a probable scenario (Fig. 11). The target sequence is lower Kopili shale. Presence of movable HC (S2) by identifying “sweet spot “needs to work out for strengthening the model in thick monotonous shale pack. The review may open up new corridor.

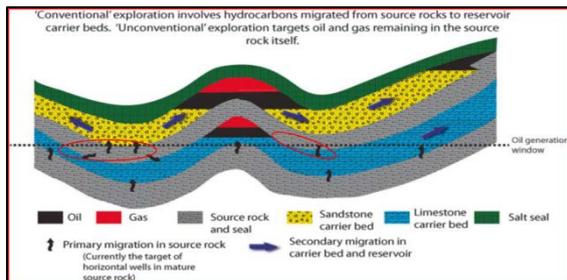


Figure 11: Co-relatable Model

The model entrapment condition:

The fractured area developed all along the thrust corridor deformed the strata within the limit of stress field. The extent of stress field depends on the extent of wave propagation. Proximal to Naga thrust corridor many areas of Discrete Fracture and strata bound fracture is evident in drilled section. For further work flow, mapping of fracture top, characterization of both identified SBF and SVF and sweet spot may lead to provide reservoir thickness and its properties , area of movable hydrocarbon (S2) limit and its extent. Thereafter, by making zonation of seal sequence above and below the fractured corridor, i.e. both top and bottom seal section with the help of seismo-facies and geo-mechanical analysis is foreseeable establishing the limit of entrapment. Evidence of hard and compact shale above the identified fractured sequence is evident in Kopili shale column in studied wells, i.e. workable seal. Based on present study, evident entrapment conditions in the envisaged set-up is strati-structural.

Authors first time in the basin given an attempt focusing this new aspect of Eocene shale. The study is constraint due to data limitation of total Kopili Formation of the field. For better understanding of fracture play prospectively, detail data require to review.

After analyzing the available data envisaged fracture network pattern is shown in Fig.12 as a schematic diagram. Parallel to sub parallel orientations (green colored) are prominent fractures developed against the main red colored fault. The genesis of networks are resultant of Miocene orogeny of Schuphen Belt. The hard and compact shales above the fractured zone may act as

both top and lateral seal. Strengthening the model, an inevitable requirement making zonation of fractured and compact zones of whole lower Kopili shale establishing presence of reservoir and seal integrity may lead a step ahead.

The study further observed that numerous sub-seismic fracture lineaments in time slice are more prominent at LCM/BCS level. However, entrapment in the litho-unit may be an issue due to presence of thin alteration of coal, shale and sand, i.e. frequent variation of litho -facies.

In the model, a schematic diagram of emerging play is thought of fracture shale sequence as a reservoir unit overlain by hard and compact impervious seal extending large area where drilling of horizontal wells can be taken up.

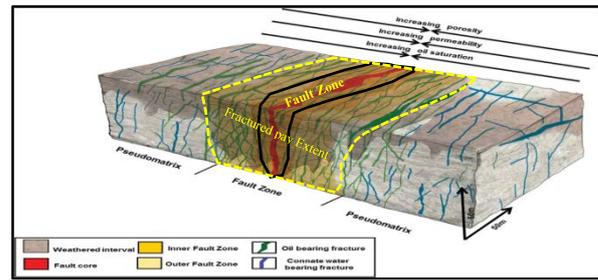


Figure 12: Worked out model

Indicative GTO and well cost:

Few deeper well GTO of Assam basin has been studied in terms of drilling / well completion days and likely expenditure. To reach net drift more than 1600m at 4000m including production testing, estimated well completion time is 200 days. For taking up drilling rig deployment require Rig. E-3000 series (variable speed). Estimated well cost is in the order of INR 55 -60 Cr.

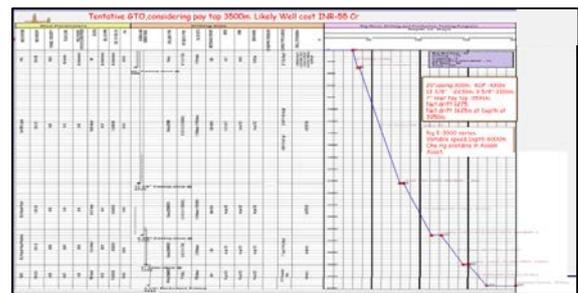


Figure 13: Indicative GTO showing well cost & achievable net drift.

Conclusion:

- (I) In present approach, a study has been carried out on identification of microfractures understanding play base hydrocarbon exploration of Eocene shales in Assam shelf.
- (II) Middle to Lower Kopili Shale sequences dominated by four different fracture system, i.e. tectonically associated, strata bound (SBF) , diagenetic and abnormal pressure fractures (sequence located in fold belt sub-thrust blocks)

- . In present study on prevailing data set, established tectonically associated medium to low angle Sub Vertical Fracture (SBF) and strata bound fractures (SBF). The findings are further strengthened by laboratory analysis
- (III) The most common shale fractured reservoir area present in the zone of inversion, i.e. Geleki inversion that require for pilot. Presence of thick shale, wherein study identified Strata Bound Fractures (SBF) and Sub Vertical Fractures (SBF) and intermittent hard and compact shale acting for seal integrity are studied. The sub-seismic micro fractures are eminent in drilled well in NNE-SSW directions all along the Naga thrust zone in Geleki area.
- (IV) The study inferred that Kopili shale may be an emerging fracture play in the area of Geleki inversion structure proximal in Naga thrust impacted zone and envisaged fracture model is shown.
- (V) Kopili Formation can be divided to two mega unit The Upper Kopili litho- unit consists of sand /shale alteration where sands are established producer as result of secondary migration. However, the Lower Kopili sequence dominated by delta front-lagoonal to shallow marine shales may become an emerging fracture play (primary migration area), the study inferred.
- (VI) In Lower Kopili, very few wells have been drilled and having limited core data. With available Lower Kopili shale data the study carried out and fracture identification marked. The finding generates leads for detail further works.
- (VII) There are some global acreages where different type of fractured reservoirs reported. As an example, Cambrian shale sequence of China province where technical evaluation of fracture type reported with comprehensive understanding for shale gas. Fracture pattern records established in the study as structural fractures, diagenetic fractures and abnormal pressure fractures and interrelationship with each other. The study further inferred that high angle shear fractures (75-90 degree) are most common and widely developed. The extended to Eocene shale of Assam and corollary drawn.
- On commercial implication, quite a number of global acreages have evidence of shale microfractures (Weald Inversion structure-Cretaceous oil, English Channel inversion Jurassic oil, etc.) acts as reservoir pay producing oil shale. An classical example in present aspect where in this field Operators are concentrating theirs efforts showing here with Chronostratigraphy superimposing with Iso VRo map of Triassic shales of Vaca Mureta Fm. Argentina shown for understanding and perception.
- (VIII) The authors has first time identified shale fracture and foresee a challenging hydrocarbon producible reservoir sequence and envisaged emerging fracture play along with cap rock in the basin.
- (IX) The hard and compact shales above the fractured zone may act as both top and lateral seal for drillable locals is envisaged.
- (X) To strengthen the model, there is a requirement of making a regional zonation of the fractured and compact zones of the complete Kopili shale section establishing entrapment
- (XI) Further to firm out fractured shale play, identification of "sweet spot" area (i.e. area of movable hydrocarbon-S2) is a must for refining thinking process. In the approach, the proportion of movable hydrocarbon can be achieved up 30%.
- (XII) Common log response of Kopili drilled wells alongside to review also i.e. presence of shale resistivity peaks within shale, low temperature anomaly (indication of fractured shear zone), zone of lowering of shallow resistivity over deep resistivity (fracture indication), Dip meter data etc.
- (XIII) Identified deeper play tentatively at 4000m, fracture length extent can possible to achieve more than 1500m by E-3000 series rig and tentative well cost expenditure envisaged INR 60 Cr. Model GTO already demonstrated.
- (XIV) Based on the model shown, Kopili shale of Geleki field is a feasible candidate. New horizon – new oil
- (XV) The study inferred that Lower Kopili shales may open up a vast area within the Assam Assam-Arakan fold belt. With the help of the existing infrastructure, drilling suitable wells in the 'sweet spot' could be commercially viable.

Acknowledgement:

The author is deeply indebted to Shri R K Srivastava Director (Exploration) and Shri Sanjay Chawla, ED-Head EXCOM for encouraging the thought process developing new play in Assam shelf. Deep sense of gratitude is further extended to A&AA Basin and RGL, Sibsagar for data support.

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4. Global acreage data available in public domain