Brittleness estimation and mineralogical analysis for evaluation of fracturability: Application to the Cambay Shale, Gujarat, India

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Abstract

Brittleness index (BI) has been considered as a key geomechanical parameter in evaluating fracturability of the shale formation for optimal extraction of hydrocarbon. BI is commonly used to quantitatively classify the brittle-ductile zones in thick shale reservoir and is considered as completion quality index. There are different methods for determining BI. In the present study, mineralogy based BI estimation method has been followed to identify brittle zones of Cambay Shale of Jambusar-Broach block, Cambay basin, India. Mineralogical composition is having a very significant role in controlling brittleness of a rock. Advanced geochemical logs like the Elemental Capture Spectroscopy (ECS) / Litho Scanner were utilized to get the continuous estimation of mineralogical composition of the Cambay Shale formation. XRD and SEM-EDS techniques are also used for mineralogical analysis of selected core samples taken from different depths. Analysis from XRD and SEM-EDS techniques reveals that the shale is composed of kaolinite, chlorite, quartz, siderite, pyrite and other minerals. Good match has been observed between the BI estimated using mineralogical composition from geochemical log and XRD analysis of core samples. Along with BI, another parameter namely fracability index (FI) has been also used for hydro-fracture evaluation. FI has been estimated continuously, combining normalized brittleness index and normalized Young's modulus. In addition to BI and FI, type of clay minerals present has some controlling role during hydro-fracture. Mineralogical analysis reveals that for hydro-fracture operation, Cambay Shale has the advantage of having kaolinite and chlorite as dominant clay minerals which are comparatively less susceptible to swelling and plastic behaviour than other clay minerals like illite. An integrated analysis of BI, FI, mineralogy, petrophysical and geochemical properties will be helpful for identification of potential target zones within thick shale. Acknowledgement The authors would like to thank Oil and Natural Gas Corporation Limited, India for providing the requisite dataset and core samples to carry out the present study.

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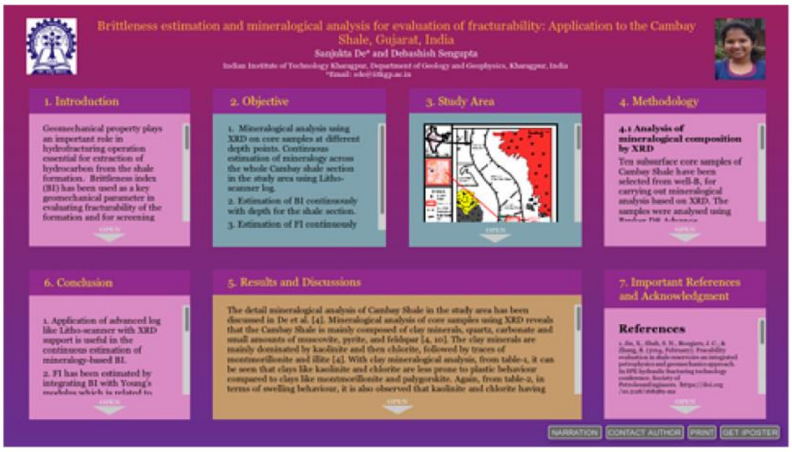

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Abstract Text:

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Along with BI, another parameter namely fracability index (FI) has been also used for hydro-fracture evaluation. FI has been estimated continuously, combining normalized brittleness index and normalized Young’s modulus. In addition to BI and FI, type of clay minerals present has some controlling role during hydro-fracture. Mineralogical analysis reveals that for hydro-fracture operation, Cambay Shale has the advantage of having kaolinite and chlorite as dominant clay minerals which are comparatively less susceptible to swelling and plastic behaviour than other clay minerals like illite. An integrated analysis of BI, FI, mineralogy, petrophysical and geochemical properties will be helpful for identification of potential target zones within thick shale.

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1. INTRODUCTION

Geomechanical property plays an important role in hydrofracturing operation essential for extraction of hydrocarbon from the shale formation. Brittleness index (BI) has been used as a key geomechanical parameter in evaluating fracturability of the formation and for screening suitable zones for hydro-facture. In the petroleum industry, two methods of determining BI are usually used for thick shale reservoirs to provide continuous BI estimation in a convenient and efficient way. One of these methods is based on mineral composition and the other method is based on the evaluation of brittleness through elastic parameters. In the present study, mineralogy-based estimation of BI has been used. Advanced geochemical log like Litho Scanner has been utilized to get the continuous estimation of mineralogical composition. Mineralogical analysis has also been done on selected core samples.

It has been mentioned by some researchers that BI alone is not enough to characterise facability as BI does not indicate rock strength or energy dissipation during hydro-fracture [1, 2, 3]. So, another parameter namely fracability index (FI) has been also considered for hydro-fracture evaluation. FI is an integration of BI and energy dissipation during hydro-fracture. FI has been estimated continuously combining normalized brittleness index and normalized Young's modulus [1]. In addition to BI and FI, type of clay minerals present has some controlling role during hydro-fracture through swelling effect and plastic behaviour [4].

2. OBJECTIVE

1. Mineralogical analysis using XRD on core samples at different depth points. Continuous estimation of mineralogy across the whole Cambay shale section in the study area using Litho-scanner log.

2. Estimation of BI continuously with depth for the shale section.

3. Estimation of FI continuously with depth for the shale section.

3. STUDY AREA

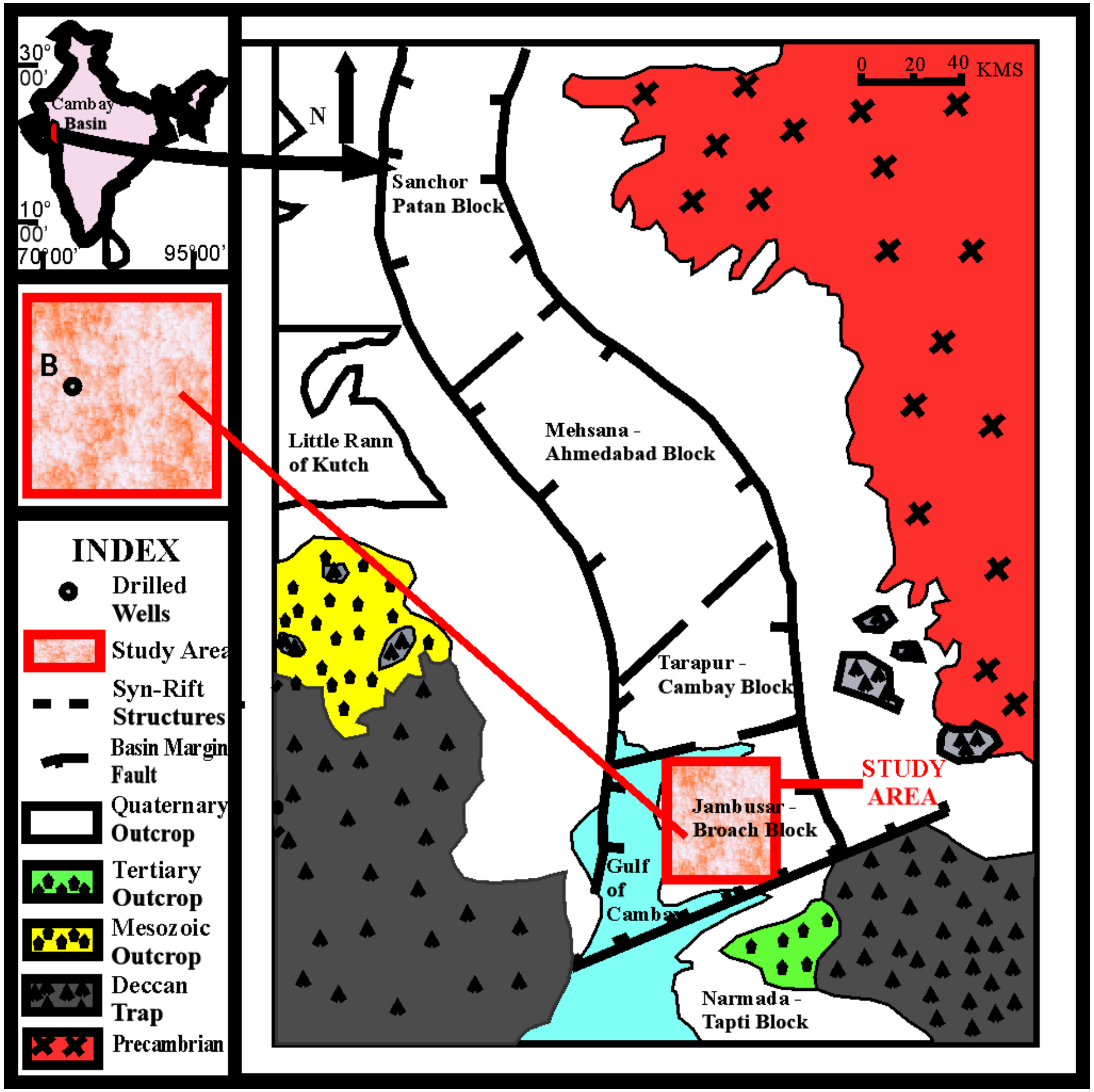

Fig. 1. The location of the study area marked in Cambay Basin [5,6].

- Major petroliferous basins of India [5].

- Located in the state of Gujarat, in the north-western part of the Indian [5].
- Intra-cratonic rift basin of Late Cretaceous to Palaeogene age [5].
- Surrounded by Saurashtracarton in the west & Kutch Basin in the northwest. Extends in the north into the Barmer Basin & continues southward into the Gulf of Cambay [6].
- The studied well is shown in Fig. 1.

4. METHODOLOGY

4.1 Analysis of mineralogical composition by XRD

Ten subsurface core samples of Cambay Shale have been selected from well-B, for carrying out mineralogical analysis based on XRD. The samples were analysed using Bruker D8 Advance instrument with a Cu target and Lynx-Eye detector. The minerals (including clay minerals and non-clay minerals) were identified by their peaks using basal spacings (d) and 2Θ for Cu Kα radiation. The identification and quantification of minerals were done using X'Pert High-Score Plus software and ICDD PDF-4 database.

4.2 Continuous mineralogical composition from Litho-scanner wireline log

Litho-scanner log provides a quantitative elemental analysis of the formation. Quantitative mineralogy (weight fractions of minerals) is derived in complex lithology using elemental weight fractions with suitable software. Dry weight fractions of minerals or group of minerals like clay obtained from Litho-scanner have been used for continuous information of mineralogical composition against depth to estimate continuous BI [7].

4.3 Estimation of mineralogy-based brittleness index

In the present work, we have used the expression for mineralogical based brittleness index (BI) estimation proposed by Jin et al. [8] considering siliceous minerals (quartz, feldspar and mica) and carbonate minerals (calcite and dolomite) as brittle minerals and is expressed as:

$$BI = \frac{W_{QFM}+W_{carbonate}}{W_{Total}} \quad \text{...................(1)}$$

Where, W_{QFM} is the sum of the weight fractions of quartz, feldspar and mica; $W_{Carbonate}$ is the weight fraction of total carbonate minerals and W_{Total} is the sum of weight fractions of all minerals.

4.4 Continuous estimation of Young’s Modulus

Sonic Scanner is a new generation sonic tool designed using latest acoustic technology. Sonic scanner log is used to derive Young’s Modulus (E) continuously across the shale formation using suitable relations [9].

4.4 Estimation of Fracability Index

Fracability index (FI) quantitively characterize the formation for effective hydraulic fracture as high brittleness but with less energy required to produce a new fracture surface. So, zone with high FI is considered to be a better fracturing candidate. In the present study we have used the relation proposed by Jin et al. [1] for continuous estimation of FI, considering critical strain energy release and fracture toughness increases monotonically with increasing Young’s modulus and is expressed as [1]:

$$FI = \frac{BI_n + E_n}{2} \text{....................(2)}$$

Where, BI_n and E_n are normalized brittleness index and normalized Young’s modulus and defined as [1]:

$$BI = \frac{BI - BI_{min}}{BI_{max} - BI_{min}}$$

...................................(3)

$$E_n = \frac{E_{max} - E}{E_{max} - E_{min}}$$

....(4)

with max and min suffixes are representing the maximum and minimum values of the parameters for the formation under study.

5. RESULTS AND DISCUSSIONS

The detail mineralogical analysis of Cambay Shale in the study area has been discussed in De et al. [4]. Mineralogical analysis of core samples using XRD reveals that the Cambay Shale is mainly composed of clay minerals, quartz, carbonate and small amounts of muscovite, pyrite, and feldspar [4, 10]. The clay minerals are mainly dominated by kaolinite and then chlorite, followed by traces of montmorillonite and illite [4]. With clay mineralogical analysis, from table-1, it can be seen that clays like kaolinite and chlorite are less prone to plastic behaviour compared to clays like montmorillonite and palygorskite. Again, from table-2, in terms of swelling behaviour, it is also observed that kaolinite and chlorite having smaller surface area and low CEC are less reactive as compared to smectite and illite. These characteristics of dominant clay minerals in Cambay Shale may turn favourable for hydro-fracture [4]. Further, mineralogical analysis infers that the presence of calcite is in traces and dolomite is absent [4]. Carbonate present is mainly in the form of siderite, which is a substantial contributor to brittle behaviour and hence has been included in the total carbonate minerals for determination of BI using equation (1).

Table 1 Liquid limit, plastic limit and plasticity indices of clay minerals [11, 12]

Mineral	Liquid limit (%)	Plastic limit (%)	Plasticity index
Montmorillonite	100–900	50–100	50–800
Illite	60–120	35–60	25–60
Kaolinite	30–110	25–40	5–70
Palygorskite	160–230	100–120	60–110
Chlorite	44–47	36–40	7–8

Table 2 Surface area and CEC of clay minerals [13, 14]

Clay mineral	Surface area (m^2/g)			Cation exchange capacity (meq/100 g)
	Internal	External	Overall	
Smectite	750	50	800	80-150
Illite	5	15	30	10-40
Kaolinite	0	15	15	1-10
Chlorite	0	15	15	<10

In fig. 2, the plots of continuous BI estimated from Litho Scanner log with depth has been shown for well-B along with data points of BI measured from to the core samples (mineralogical analysis). The plots clearly indicate a good agreement between Litho-Scanner and XRD derived results supporting the suitability of using Litho-Scanner log for continuous mineralogy. The BI ranges from 0.1 to 0 .75 indicating the presence of some brittle zones with BI> 0.48. The plots of variation of BI and FI with depth for well-B has been shown in fig. 3. The FI varies in the range of 0.20-0.88 The variation of BI and FI are similar in major part of the shale section. This is also clearly reflected in the plot of FI vs BI as shown in fig. 4. Fig.5 is a cross plot of BI and E, showing the direction of increasing FI. So, for Cambay Shale formation in the studied area, both FI and BI can be used reasonably well for predicting suitable target zones for hydraulic fracture.

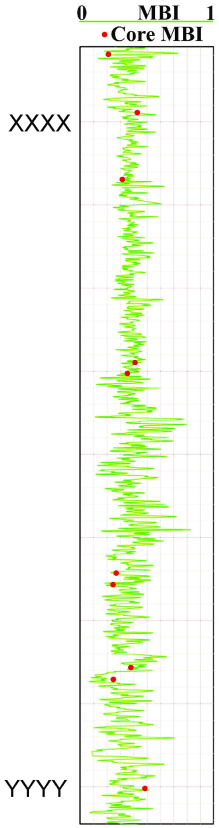

Fig. 2. A plot of continuous BI with depth estimated using Litho-Scanner log mineralogy has been shown for well-B. The data points of BI estimated from core sample mineralogical analysis have been marked with red dots.

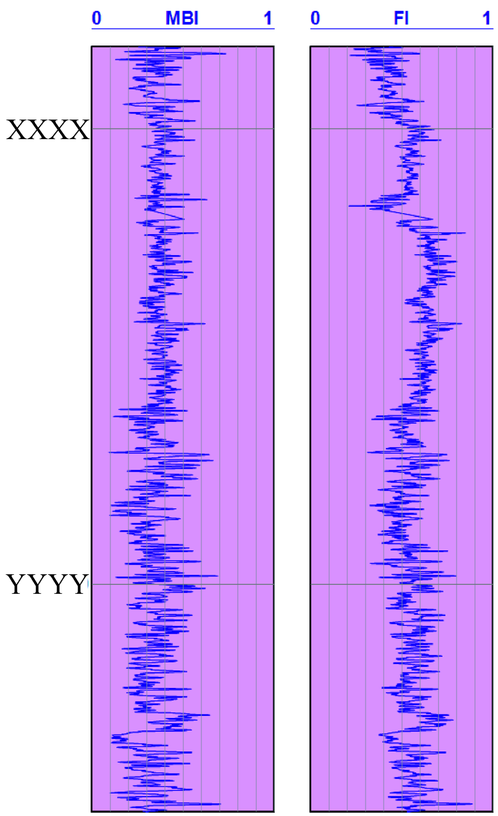

Fig. 3. The plots of variation of BI and FI with depth for well-B.

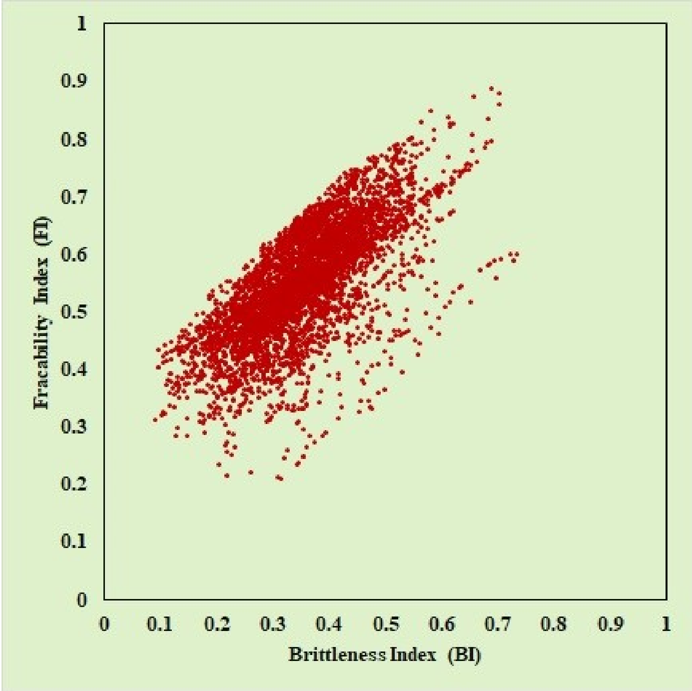

Fig. 4. The cross plot of BI and FI for well-B in Cambay Shale section.

Fig.5. Cross plot of BI and E for well-B, showing the direction of increasing FI.

6. CONCLUSION

1. Application of advanced log like Litho-scanner with XRD support is useful in the continuous estimation of mineralogy-based BI.

2. FI has been estimated by integrating BI with Young's modulus which is related to the critical strain energy release rate.

3. Mineralogical analysis reveals that for hydro-fracture operation, Cambay Shale may has the advantage of having kaolinite and chlorite as dominant clay minerals which are comparatively less susceptible to swelling and plastic behaviour than other clay minerals like illite.

5. An integrated analysis of BI, FI, mineralogy, petrophysical and geochemical properties will be helpful for the screening of potential target zones within thick Cambay Shale.

7. IMPORTANT REFERENCES AND ACKNOWLEDGMENT

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