Analysis of Cleats in Coal Bed Methane wells from Micro Resistivity Image and Cross Dipole Array Acoustic Log

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Cleat density and its direction, in situ horizontal stress, stress anisotropy

Abstract

Coal Bed Methane (CBM) productivity from coal seams is a function of many factors of which coal bed permeability, gas content, saturation, critical desorption pressure, coal seam thickness, depth of burial and hydrogeological conditions are the major influencing parameters.

Natural fractures in coal, also known as cleats, are the primary flow path within a CBM reservoir and high cleat density is a major facilitator for good flow of methane from such reservoirs. Analysis of Hi-tech logs can provide a deep insight to cleat system distribution and orientation. The primary cleat direction can be obtained from micro resistivity image log. In-situ horizontal stress direction can be obtained from cross dipole array acoustic logs with the help of anisotropy analysis. The fast azimuth curve (FACR) indicates the direction of maximum horizontal stress. Cleat direction and its relation with in-situ horizontal stress directions define the fluid potential through the cleats and this type of information can be effectively utilized for designing the completion and production strategy. In the present study, a well from South Karanpura coalfield has been analyzed for cleat density and orientation, stress direction and identification of potential permeable coal layers. Acoustic data obtained from 'cross dipole array acoustic logging tool' has been processed for geo-mechanical properties of the coal seam. Based on this study, six permeable intervals having flow potential were identified. However, actual well test results indicated low flow of methane. Hence, though cleat concentration and orientation can be well estimated form hi-tech logs which is a very useful tool for object identification and designing production strategy, the analysis is to be used with caution and in conjunction with other geological parameters for optimized production planning.

Introduction

Coal is a source rock and as well as reservoir rock. Primary porosity or inter granular porosity in coal seam is negligible (Close, 1993). Low permeability coal matrix is partly connected by high permeable orthogonal and near sub vertical fractures with respect to bedding plane called cleats. Elongated continuous fractures are called face cleats and shorter length fractures are called as butt cleats. Permeability anisotropy exists in coal seams. **Figure 1a**shows a schematic diagram of natural fracture system in a coal seam (Paul and Chatterjee 2011a,b).

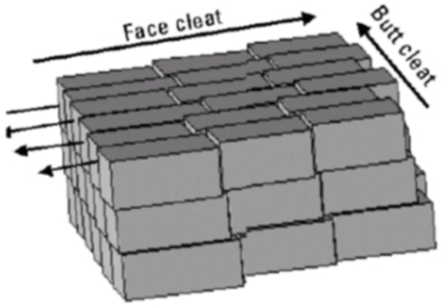

Figure1a: Schematic diagram of cleat system in Coal

CBM productivity depends on coal thickness, coal rank, gas content, ground stress, coal reservoir pressure and hydrodynamic conditions (Si et al., 2001; Lou, 2004, Huang et al., 2010). According to the data from CBM production test wells from previous study, (e.g. Liu et al., 2008, Gao et al., 2012) the gas productivity is mainly influenced by the original permeability, coal thickness, burial depth, gas content and saturation, critical desorption pressure and hydro-geological conditions (Laubach et al.,1998) Since anisotropy exists in all coal reservoirs, variation in geologic conditions even within a small range, often lead to a big difference in productivity of CBM wells Hence, to identify the main controlling geological factors guiding CBM well productivity in specific regions have deep significance in determining the exploitation strategy.

The present study carried out in one exploratory well of South Karanpura CBM block(**Figure1b**) and drilled to a depth of 1034m (with the objective of exploring the coal seams of Barakar formation) specifically focuses only on cleat density and cleat orientation along with stress direction from analysis of hi-tech logs. This integrated evaluation approach in identifying a cleat network system and its relation to present day near wellbore stresses is a key factor in assessing a zone for its potential for production and further planning of completion design.

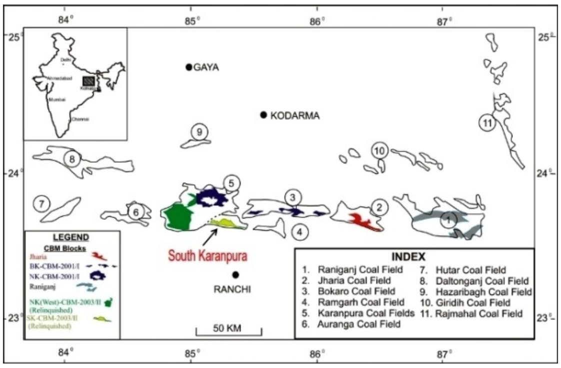

Figure1b: Showing the location map of study area

Complete set of conventional and high tech logging tools like 'micro resistivity image' and 'cross dipole array acoustic' tool are recorded in the well.Conventional log data are processed by *Geographix* software of Landmark for determination of ash content in coal only. Ash content in geological formation other than coal is not applicable. Resistivity image data is processed for fracture analysis. Acoustic data is processed for two purposes: (a) to estimate geo-mechanical properties of coal seam and sedimentary rock below and above seam floor and roof respectively, (b) to obtain direction of in-situ horizontal stress by anisotropy analysis.

A total of 45 coal seams are identified from 900m depth interval. Observed coal bedding data indicates the azimuth orientation is towards South. **Figure 2**below depicts the rose diagram of the observed coal bedding.

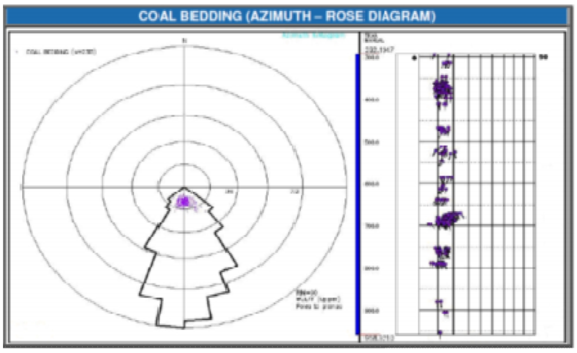

Figure 2: Azimuth rose diagram of the observed coal bedding (Wulff upper hemisphere plots)

A total of 1416 cleats have been noticed within 45 coal seams. Anisotropy study on acoustic data provides direction of maximum horizontal stress towards NW-SE.

Conventional logs

Conventional tools like density, gamma ray, neutron, sonic and resistivity have been used to delineate the coal seams. Log motifs foracoal layer in the depth interval 751-769m are presented in **Figure 3**. This thick coal layer known as Argada'A', is characterized by resistivity of 2000 ohm-m, average gamma ray (GR) of 75 API and density of 1.5 gm/cc. The compressional and shear slowness is observed as 124µs/ft and 295µs/ft respectively.

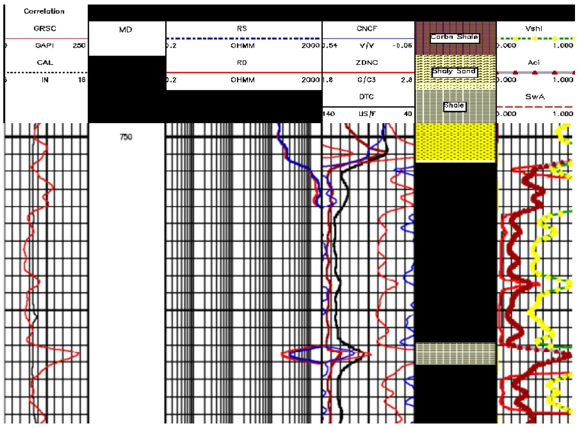

Figure 3: Ash content against the coal bed in the extreme right track

Presence of cleats in coal seam is not visible through conventional logs and image logs are of great importance foritsidentification.

Geo-mechanical Properties

Table 1: Geo-mechanical properties from a well, South Karanpura coalfield

DEPT	BMOD	POIS	SMOD	VPVS	YMOD	
749.275	22.639	0.215	15.909	1.66	38.669	
750.113	25.103	0.231	16.468	1.69	40.539	
751.027	34.269	0.31	14.907	1.906	39.058	
751.332	20.193	0.331	7.683	1.99	20.454	
751.408	17.449	0.337	6.407	2.02	17.123	
751.561	12.978	0.349	4.371	2.079	11.789	ARGADA A COAL
752.018	8.187	0.373	2.276	2.221	6.249	
753.085	9.561	0.372	2.674	2.216	7.339	
754.304	7.098	0.372	1.981	2.218	5.436	
755.294	6.467	0.377	1.737	2.249	4.783	
756.209	6.146	0.391	1.443	2.365	4.015	
757.276	6.789	0.396	1.514	2.412	4.227	
758.266	7.12	0.374	1.96	2.229	5.385	
759.333	6.467	0.393	1.492	2.381	4.156	
760.476	6.198	0.385	1.537	2.316	4.259	
761.39	7.184	0.403	1.492	2.479	4.187	
762.305	12.864	0.372	3.602	2.215	9.884	
763.524	7.709	0.374	2.126	2.227	5.84	
764.362	6.8	0.392	1.576	2.377	4.388	
765.353	7.325	0.409	1.416	2.55	3.992	
766.267	8.371	0.396	1.876	2.408	5.236	
767.334	6.96	0.408	1.372	2.531	3.861	
768.248	6.953	0.4	1.49	2.45	4.171	
769.239	9.438	0.376	2.573	2.247	7.073	
769.696	22.337	0.321	9.126	1.947	24.095	
770.306	29.713	0.289	14.563	1.837	37.539	
771.373	22.81	0.232	14.911	1.692	36.729	
772.287	29.556	0.282	15.108	1.814	38.725	
773.201	26.527	0.276	13.937	1.799	35.58	
774.04	24.966	0.286	12.455	1.827	32.038	

Table 1 presents the rock properties of coal horizon Argada 'A'. VP/VS ratio varies as 2.079–2.479. VP/VS ratio and Poison's ratio are comparatively high against coal seam indicating the presence of cleat. Bulk modulus (BMOD) ranges from 6.146 to 12.864GPa, Shear modulus (SMOD) ranges from 1.372 to 2.276GPa and Young's modulus (YMOD) ranges from 3.861 to 7.073GPa.These three elastic moduli are of low value.

Ash content determined from processed log data in this zone is noticed to vary from 10 to 30% (**Figure 3**).

Resistivity Image Log Analysis

Type of cleat network, degree of cleating and its connectivity in respect of permeability varies from one coal seam to other. Micro resistivity image analysis is a useful tool used to identify the cleats in coal seams.

Micro resistivity image logs have good vertical resolution in the order of 0.2 inches and the image data quality is so good that identification of cleats network can be observed through naked eye. Dip angle value and its orientation in terms of cleat and fracture analysis enable the interpreter to do the better performance. Natural fractures, drilling induced tensile fractures, borehole breakout can be distinguished easily using resistivity logs. Very few induced fractures are observed over the complete interval.

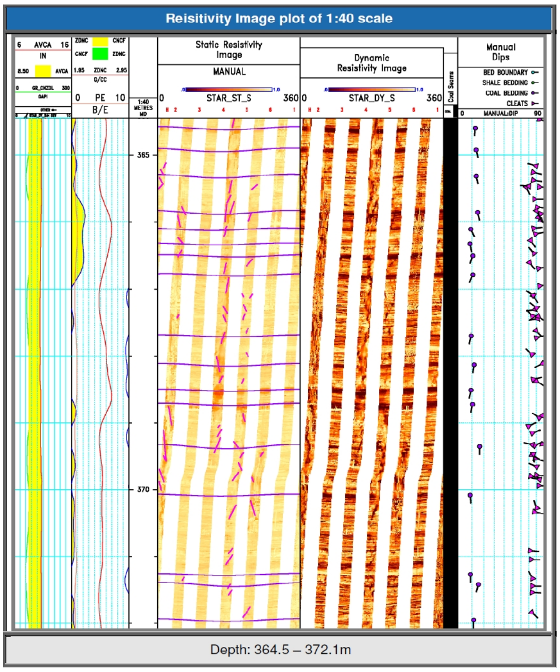

Figure 4: Small scale cleats with limited verticalconnectivityin unit- 1

The degree and variation of cleat development is clearly visible on the image logs. Two different types of cleats are observed. The small scale ones are concentrated mostly within individual coal bands and the large scale cleats have been observed to be cross cutting multiple bandings and thereby resulting in greater vertical connectivity.

Total of 1416 cleats are interpreted from resistivity images over the interval from 45 coal seams. 6 units are identified of which two coal units (unit-1 and unit-2) are discussed.

Cleat orientation from image logs are picked as fracture traces as plotted in **Figure 4** and **Figure 5** and their orientation displayed as tadpole plots (track 6 from left), indicating dip and strike of the face cleats.

Figure 4 indicates that there are only 44 cleats in the unit-1 and having small scale vertical connectivity as observed in dynamic resistivity image.

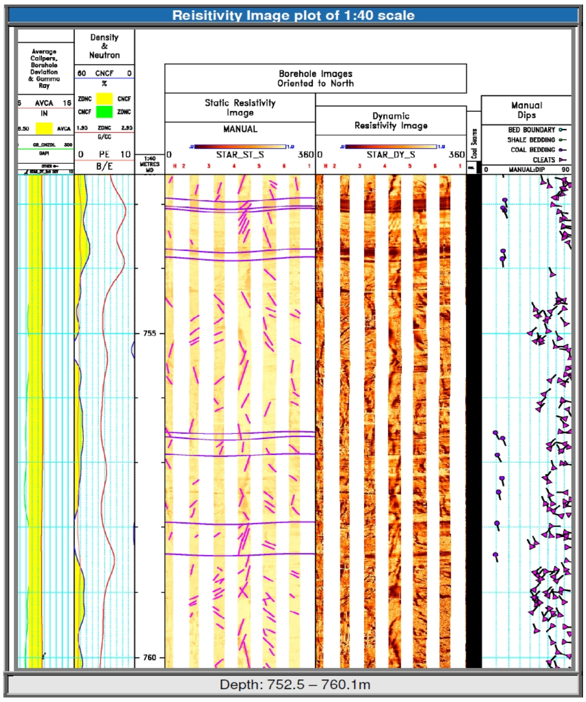

Figure 5: Larger scale cleats with good vertical connectivity in unit-2

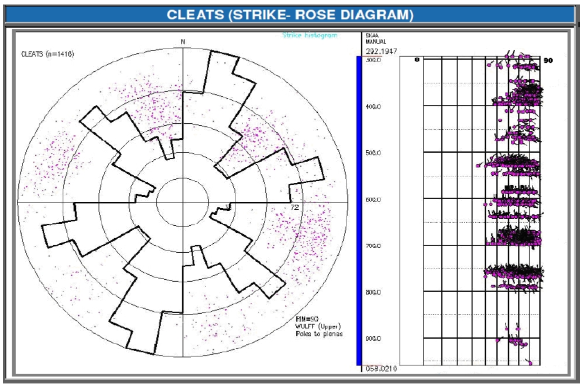

Figure 6: Rose diagram of observed cleats(Wulff upper hemisphere plots) in well XYZ. Most of the cleats have dip magnitudes from 45° to 90°

Figure 5 indicates that there are only 153 cleats in the unit-2 and these have large scale vertical connectivity as observed in dynamic resistivity image.

Rose diagrams displaying the overall Strike orientation of the cleats of all the individual coal seams are plotted in **Figure 6**.

Anisotropy Analysis

With the help of 'cross-dipole array acoustic logging technology' anisotropy can be measured in the formation. The anisotropy can be obtained from the commonly known Transverse Isotropic (TI)formations by putting the borehole perpendicular to the TI formation's symmetry (principal) axis, i.e., a TI formation having three mutually perpendicular "principal directions", of which two span the plane perpendicular to the borehole axis.

When a flexural wave propagates along a vertical borehole surrounded by an azimuthally anisotropic formation, the wave splits into two horizontally polarized flexural waves (shear wave splitting) with orthogonal polarization directions and different velocities.

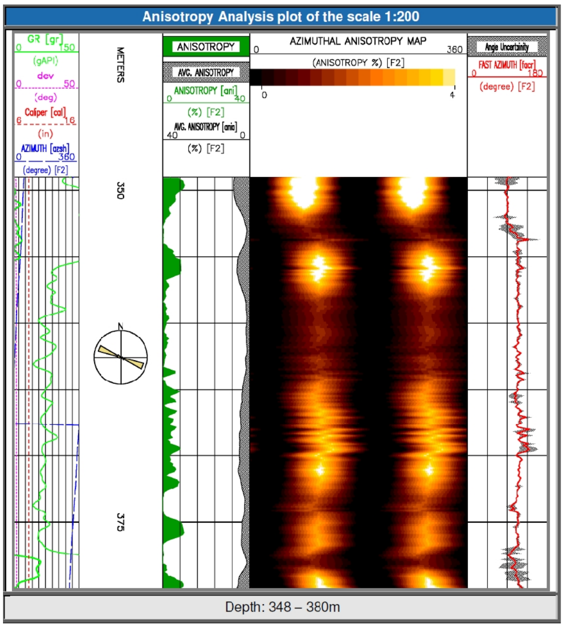

Figure 7: Anisotropy mapping with 3.5% average anisotropy of unit-1

Anisotropy analysis is done for the entire interval of 900 m for the well. The fast azimuth curve (FACR) provides the direction of the maximum horizontal stress, which is oriented towards NW-SE. This observation matches with one of the strike orientations of the face cleats. The anisotropy data shows high anisotropy corresponding to the coal seams. The high cleat density in the coal seams results in the high anisotropy which supports our interpretation of the cleats from the micro resistivity image data. The anisotropy data is plotted in **Figure 7** and**Figure 8** showing the azimuthal anisotropy map, the average azimuthal anisotropy and the fast azimuth.

Figure 7 indicates that anisotropy analysis of the acoustic data over the unit-1 with 3.5% average anisotropy and the Fast Shear Azimuth is around N115°, which is the direction of maximum horizontal stress. **Figure 8** indicates that anisotropy analysis of the XMAC data over the unit-2 with 6.1% average anisotropy and the Fast Shear Azimuth is around N 111° which is the direction of maximum horizontal stress.

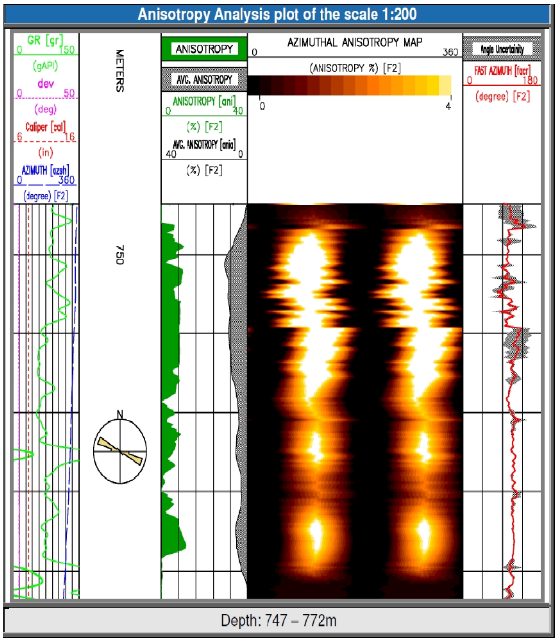

Figure 8 Anisotropy mapping with 6.1% average anisotropy of unit-2

Integration of micro resistivity and acoustic image log

It is known that if maximum horizontal stress (SH) is parallel to the face cleat system, then the cleat system open and helps in primary flow and increases coal permeability. Hence, the knowledge of present day stress orientation and relation with face cleat system is an important factor for CBM exploration.

In the present case study, from resistivity analysis, it is found that unit-2 (coal seam) has highest cleat density than unit-1. Acoustic log shows that unit-2 has more average anisotropy than unit-1. This is to be noted that both the independent measurements such as: resistivity image log and sonic log shows similar trend in terms of cleat density. From the above analysis,a distinctcriteria to select coal seamsintervals for optimum production hasemerged where coal seam unit-2 with high cleat density~~,~~ and high flow path, should be given priority over other intervals while selecting coal beds for production. If maximum horizontal stress (SH) is parallel to the face cleat system, then the cleat system open and helps in primary flow and increases coal permeability. Therefore, present day stress orientation and relation with face cleat system is important for CBM exploration.

This study has been carried out without considering the other geological factors for production optimization. Well test results indicated low flow rate of methane and notviable for commercial production. Hence, the above cleat studies, though a very useful method for identification of potential zones, it must not be used in isolation. Rather, it should be used in conjunction with other parameters such as: permeability, gas content, saturation, maceral content, proximate analysis, reservoir pressure, hydrodynamic condition etc. for production optimization

Conclusions

Micro resistivity image log data and cross dipole acoustic data are acquired over aninterval of 900 m in a particular well of South Karanpura coalfield. From log interpretation a total of 45 coal seams are identified. The observed coal bedding data indicates dominant south oriented dip azimuth. A total of 1416 cleatshave been identified from resistivity images over the interval from 45 coal seams. The major strike orientations of the cleats identified from the image are NW-SE, NNE-SSW and ENE-WSW. The maximum horizontal stress direction (NW–SE) identified from anisotropy analysis coincides with one of the strike direction of the interpreted cleats. Anisotropy data shows high anisotropy corresponding to the coal seams with high cleat density. Based on thickness, cleat density and average anisotropy, 6 units have been identified as potential prospects. However, though integration of micro resistivity and cross dipole array acoustic image logs is a very powerful method for identification of potential zones from different coal seams as discussed, the same needs to be further substantiated with other geological parameters for production optimization.

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