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Microscale assessment of 3D geomechanical structural characterization of gondawana shales

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ABSTRACT

The microscale characteristics of gray and black shale samples collected from two different locations of Singrauli coalfield, Madhya Pradesh, India were investigated using scratch tester and Raman stress mapping. The failure events were analyzed for the entire scratch track. The areas of critical point were identified based on the acoustic emission, tangential force measurement along with characterization methods Scanning Electron Microscopy (SEM) and Raman spectroscopy. The SEM studies at the critical points indicate the failure in black and gray shale are completely different. The critical points are analyzed by confocal Raman spectroscopy for measuring the Raman spectral shifts and Raman stress mapping. The Raman spectra of disordered D band are used for quantifying the stress in the entire scratch track. Micro scratch test performed in different directions along with critical point regions of black and gray shale is compared. Raman spectral shifts of D band are measured and compared for the strained regions. This reveals the 2D Raman imaging of black and gray shale as a proxy for characterizing the stress inversion. Correspondingly the Raman peak intensity ratios along with full width at half maximum (FWHM) were calculated for the critical regions.

1. Introduction

It is critically important to understand the heterogeneous geomechanical properties of shale deformation and fracturing characteristics. Defining the degree of heterogeneity of shale has always been a complex area of study. Therefore, understanding the fundamental fracture mechanism of shale holds the key to ensuring effective fracturing with minimal environmental and socioeconomic consequences. Many studies related to fracturing research as well as industrial experience show that certain reservoirs have a tendency to develop fracture branching which is not aligned with the maximum principal stress, ultimately leading to fracture complexity. The fracability of reservoir is determined by differential horizontal stress ratio, provides a measure for selecting the frackable area or preferred area for performing hydraulic fracturing. Differential horizontal stress ratio provides a parameter in determining how the reservoir tend to fracture. If the differential horizontal stress ratio is high the hydraulic fractures start growing in parallel to the maximum horizontal stress without intersecting planes. The crack grows vertically with any cracking branching or reservoir doesn't show tendency for secondary crack growth. If the differential horizontal stress ratio is less the hydraulic fractures tend to develop in variety of directions and intersect. The crack branching phenomenon occurs because of multidirectional fracture network (Gray et al., 2012). The industry faces key challenges with regard to the completion of the design and analysis of wells and hydraulic fracturing due to issues such as variation in depth, textural heterogeneity and mineralogy, which are not well understood. The degree of the heterogeneity of shale formations poses challenges during economic production. The degree of shale heterogeneity depends on many factors such as its mineralogy, texture and in-situ and thermomechanical stress states (Akono, 2013). Understanding the high degree of heterogeneity, anisotropy and brittle nature of shale is crucial for tackling the problems associated with stress percolation during shale exploration (Kantipanyacharoen et al., 2011). Currently, mechanical testing methods such as micro-scratch techniques are being used to measure the fracture characteristics of rocks (Akono and Ulm, 2011).

The micro-scratch test can be performed along different orientations on the sample and provides more information than any other technique about the fracture properties of shale. Moreover, micro-scratch experiments require minimal time for sample preparation and testing. The main advantages of micro-scratch experiments are that the prepared sample size is small and maximum information about the heterogeneous behavior of the rock can be obtained from a small number of core analyses. Nanoindentation testing provides information about various dimensions such as the Young's modulus and hardness and load v/s displacement of the materials tested (Mahabadi et al., 2012;

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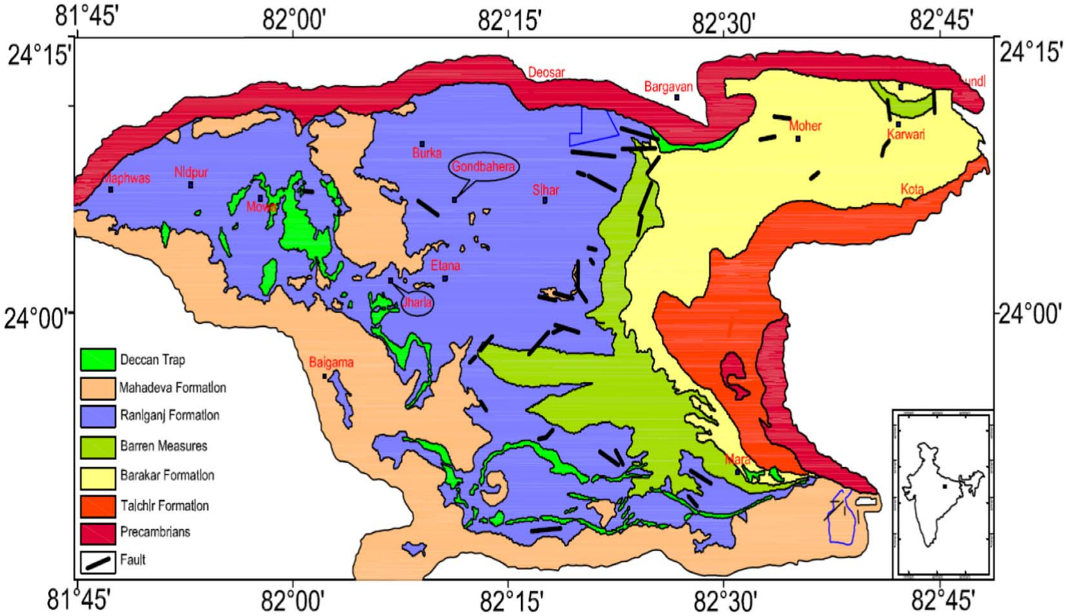

Fig. 1. Geological map of the Singrauli coal field showing the area of the study (link: www.fossil.energy.gov/international/Publications/ucg_1106_gsi.pdfCoal Resource Position in India, 2011).

Shahidzadeh-Bonn et al., 2005).

Lab scale geomechanical experiments provide the information required for the calculation of the mechanical properties of the rock. However, a proper understanding of the mechanical behavior of rocks requires a thorough characterization of the rock texture through mineralogy studies. The basic concepts of stress contrast, stiffness contrast and fracture toughness variations in shale need to be understood and analyzed. Clarity about the role of macerals, textures and fabric related mechanical behavior is necessary for understanding the modes of fracture and failures in shale formations (Bernard et al., 2012; Gorbanenko and Ligouis, 2014; Guedes et al., 2010; Hutton, 1987; International Committee for Coal Petrology, (ICCP), 1993; López-Honorato et al., 2010; Potgieter-Vermaak et al., 2011). An understanding of the crack nucleation based on load application and related 3D strain field around the load-affected area is also important. With recent advancements in image analysis, Raman spectroscopy analysis is being widely used to understand factors such as grain orientation, texture, anisotropy and internal stress (Becker et al., 2007; Beyssac et al., 2003; Ferrari and Basko, 2013). Raman analysis is used for both in-situ and ex-situ experimental measurement of scratched and indented areas, including 3D strain field around the load area (Dumpala et al., 2014; Ghosh et al., 2008; Tselev et al., 2014). Raman micro image analysis shows a clear distinction and differentiation in the areas of critical stresses developed for different macerals (Kang et al., 2005; Guo and Marc Bustin, 1998).

Since the geomechanical behavior of shale depends on its texture and mineral composition, we propose a novel approach that would enable a comprehensive understanding of the behavior of shale fractures. Raman spectroscopy is widely used in determining the shale maturity by correlating with vitrinite reflectance (Cheshirea et al., 2017; Lünsdorf, 2016; Sauerer et al., 2017). But we discuss about the combination of Raman spectroscopy and geomechanical experimental studies in understanding stress mapping of shale. The combination of Raman spectra and micro scratch test helps in linking fracture toughness behavior with heterogeneities of shale. Raman spectral shift are useful in understanding the nature of stress inversion based on peak shifting and stretching and identification of weak spot during reservoir stimulation along with orientation of stress.

The present study aims to analyze shale structural complexity and stress percolation based on geomechanical behavior in lab scale studies. Earlier studies have focused on understanding the global heterogeneity of shale based on nano and micro scale experimental inputs in computer modeling (Burnley, 2013; Mahabadi et al., 2014). It was felt that some improved characterization studies such as Raman spectroscopy would help in better prediction of heterogeneity. Microscratch provides more information on the directionality of fracture behavior with finer reasons for failures based on acoustic emission and by image processing techniques. Therefore, the main intention of this study is to scale the fracture toughness properties on a small test sample and evaluate the consistency of the estimates based on mean Raman shift on individual scratches with respect to the area-normalized standard deviation of the estimates. Therefore, in the present study, chemical analysis is applied to stress mapping along the tracks of scratch to understand the fracture behavior of shale in relation to its texture, anisotropy and mineralogy. Different types of shale such as black and gray are characterized utilizing Raman spectroscopy and their heterogeneity is analyzed along different orientations.

2. Materials and methods

2.1. Materials

The black shales was obtained at a depth ranging from 596 m to 599 m at Kapuria, Jharia C/F BCCL while the gray shale was obtained at depths ranging from 329.7 m to 330.9 m from Gondhbehra, Singrauli (Madhya Pradesh), India. The black and gray shale sample for this study was obtained from the Raniganj Formation and this formation is underlined by the Barren Measures, Barakar and Talchir Formation, as shown in Fig. 1. Black shale samples were collected from the Jhingurdah top seam and the gray shale was obtained from the Jhingurdah bottom seam. An east-west trending boundary fault (an offshoot of the Son Narmada lineament) covers the northern limit of the study area and four other faults have been deciphered within the main block. The seven regions of coal seams that occur in the Barakar Formation fall within the depth range of 244.23 m–606.75 m (Misra and Singh, 1990) with the rank of the coal ranging from A–F (Mukhopadhyay et al., 2010; Prakash et al., 2014; Raja Rao, 1983). Structurally, this coal block strike NE-SW with minor swings and a low dip of 3° to 5° towards the SE. The throw of the major fault ranges from 100 m–120 m, trending NE–SW with throw towards the west. For the other three faults, the throw